This document is a portion of the *Draft Cruise Ship Discharge Assessment Report* (*Draft Report*), published on December 20, 2007. The reference number is EPA 842-R-07-005. The entire *Draft Report* can be accessed at http://www.epa.gov/owow/oceans/cruise_ships/disch_assess.html.

Draft Cruise Ship Discharge Assessment Report

Section 2: Sewage

December, 2007

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Sewage from vessels, also known as "black water," generally means human body wastes and the wastes from toilets and other receptacles intended to receive or retain body wastes. On most cruise ships, sewage is treated using a marine sanitation device that biologically treats and disinfects the waste prior to discharge. On some cruise ships, especially many of those traveling to Alaska, sewage and often graywater are treated using Advanced Wastewater Treatment systems that provide higher levels of biological treatment, solids removal, and disinfection as compared to traditional marine sanitation devices.

This section discusses the current state of information about vessel sewage, the laws regulating sewage discharges from vessels, the types of equipment used to treat sewage generated on cruise ships and how well they remove various pollutants, the potential environmental impacts of cruise ship sewage discharges, and federal actions taken to address sewage from cruise ships.

2.1 What is sewage from vessels and how much is generated on cruise ships?

Sewage from vessels, also known as "black water," generally means human body wastes and the wastes from toilets and other receptacles intended to receive or retain body wastes. On some ships, medical sink and medical floor drain wastewater is commingled with sewage for treatment.

Cruise ship sewage systems generally use fresh water to reduce corrosion, and vacuum flushing and conveyance to reduce water use. According to responses to EPA's survey of 29 cruise ships operating in Alaska in 2004, the average amount of water needed per toilet flush is 0.3 gallons. Only one of the ships surveyed uses seawater in their sewage system; this gravity system uses 1 gallon of seawater per toilet flush. For comparison, the latest water-saving, high-efficiency domestic toilets for land-based use typically use about 1.3 gallons per flush.

Sewage generation rates reported in response to EPA's 2004 survey ranged from 1,000 to 74,000 gallons/day/vessel or 1.1 to 27 gallons/day/person. EPA is not able to independently confirm the accuracy of these estimated rates. Average reported sewage generation rates were 21,000 gallons/day/vessel and 8.4 gallons/day/person (see Figure 2-1). There appears to be no relationship between per capita sewage generation rates and number of persons onboard (see Figure 2-2).

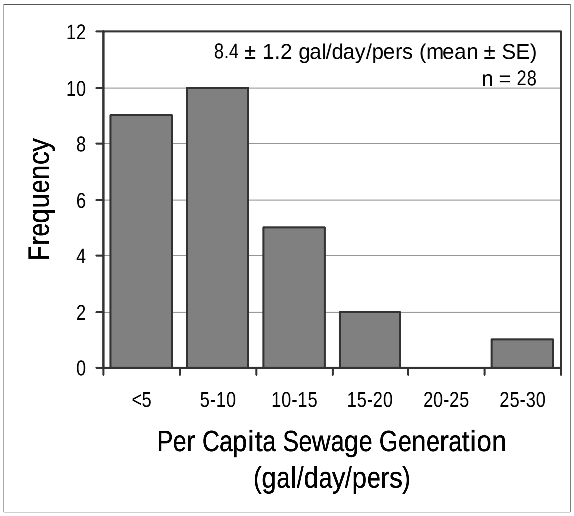

Figure 2-1. Per Capita Sewage Generation as Reported in EPA's 2004 Cruise Ship Survey

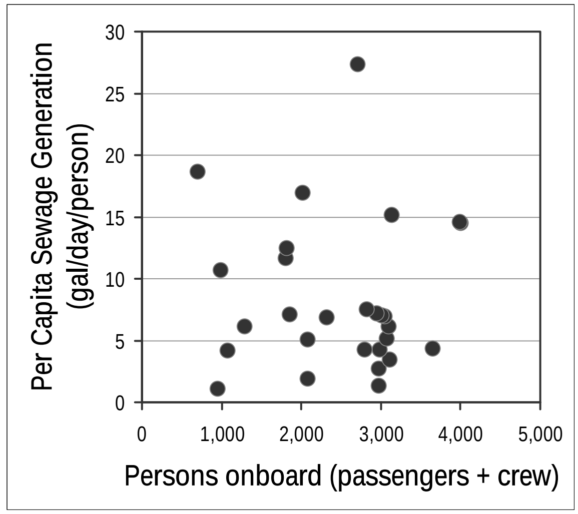

Figure 2-2. Sewage Generation by Persons Onboard as Reported in EPA's 2004 Cruise Ship Survey

During EPA's 2004 sampling of four ships with Advanced Wastewater Treatment systems (AWTs), sewage generation was measured on one ship at 17 gal/day/person (EPA, 2006a). On other ships, measurements were made of sewage plus graywater sources treated by the AWT (see Section 3 for more information on graywater).

Treated sewage discharge rates are nearly equivalent to sewage generation rates. Differences between these two rates are attributed to the volume of wastewater treatment sludge, if any, that is removed during wastewater treatment (see subsection 2.3.3 below).

Cruise ship capacity to hold untreated sewage varies significantly. According to responses to EPA's 2004 cruise ship survey, sewage holding capacity ranges from 0.5 to 170 hours, with an average holding capacity of 62 hours.

2.2 What laws apply to sewage from cruise ships?

2.2.1 Clean Water Act Section 312

Section 312 of the Clean Water Act (CWA; 33 U.S.C. § 1322) requires that vessels with installed toilet facilities be equipped with an operable marine sanitation device (MSD), certified by the Coast Guard to meet EPA performance standards, in order to operate on the navigable waters of the United States, including the territorial seas. CWA section 312 also establishes procedures for the designation of no-discharge zones for vessel sewage. Section 312 is implemented jointly by EPA and the Coast Guard. EPA is responsible for developing performance standards for MSDs and working with states to establish no-discharge zones. The Coast Guard is responsible for certification of MSDs prior to sale, introduction or delivery into interstate commerce, or import into the United States for sale or resale. States may not adopt or enforce any statute or regulation of the state or a political subdivision with respect to the design, manufacture, installation or use of MSDs (except on houseboats). The Coast Guard and states are vested with authority to enforce the requirements of section 312. Persons who tamper with certified MSDs or sell non-certified MSDs, or who operate vessels required to have MSDs but do not, are subject to statutory penalties of up to $5,000 and $2,000, respectively, for each violation.

Marine Sanitation Devices

The term "marine sanitation device" (MSD) means equipment for installation onboard a vessel which is designed to receive, retain, treat, or discharge sewage, and any process to treat such sewage. CWA section 312(a)(6) defines sewage as human body waste and the wastes from toilets and other receptacles intended to receive or retain body waste. There are three types of MSDs recognized by the Coast Guard:

- Type I MSDs are flow-through treatment devices that commonly use maceration and disinfection for treatment of the sewage. Type I devices may be used only on vessels less than or equal to 65 feet in length. EPA's performance standard for Type I MSDs is an effluent with a fecal coliform count not to exceed 1000 per 100 millimeters of water, with no visible floating solids.
- Type II MSDs also are flow-through treatment devices, generally employing biological treatment and disinfection. Some Type II devices use maceration and disinfection. Type II MSDs may be used on vessels of any size. EPA's performance standard for Type II MSDs is an effluent with a fecal coliform count not to exceed 200 per 100 milliliters of water and total suspended solids no greater than 150 milligrams per liter of water.
- Type III MSDs are holding tanks, where sewage is stored until it can be properly disposed of at a shore-side pumpout facility or out at sea (beyond three miles from shore). Type III MSDs also may be used on vessels of any size. EPA is not aware of any cruise vessels that use Type III MSDs. However, a Type II MSD may serve as a Type III MSD if the vessel maintains all waste products onboard the vessel and transfers to a shore-side facility or discharges at least three nautical miles offshore.

The Coast Guard is responsible for certification of MSDs based on EPA's performance standards (listed above). The Coast Guard can certify a product line of MSDs for vessel installation and use if that product line complies with Coast Guard design and testing criteria (33 CFR Part 159), as confirmed by testing conducted at a qualified independent laboratory. After Coast Guard review and approval, each MSD model is designated an approval number ("certification"), typically valid for five years. MSDs manufactured before the certification expiration date are deemed to have met Coast Guard standards and may be installed on vessels; MSDs manufactured after the expiration date do not meet Coast Guard approval. Under Coast Guard policy, foreign-flagged vessels may use MSDs that have received a compliance test certificate under Annex IV of MARPOL (discussed below). The Coast Guard does not test the effluent from certified MSDs once installed onboard a vessel (except in Alaska under Title XIV; see subsection 2.2.3 below).

No-Discharge Zones

CWA section 312(f) authorizes the establishment of no-discharge zones (NDZs), areas in which discharges from vessels of any sewage, whether treated or not, are prohibited. States may establish an NDZ for some or all of their waters if EPA determines that adequate facilities for the safe and sanitary removal and treatment of the sewage are reasonably available. States also may request that EPA establish NDZs by rulemaking (1) if EPA determines that the protection and enhancement of the quality of the waters require such a prohibition, or (2) to prohibit the discharge of vessel sewage into a drinking water intake zone. There are currently 65 NDZs in the United States covering 113 waterbodies; 62 of these NDZs were established by states.

2.2.2 The International Convention for the Prevention of Pollution from Ships

The principal international convention addressing discharge standards for vessel sewage is Annex IV to the International Convention for the Prevention of Pollution from Ships (also known as MARPOL). Annex IV defines sewage as “drainage from medical premises, toilets, urinals, spaces containing live animals and other waste waters when mixed with sewage waste streams.” Although Annex IV was adopted in 1973, the Annex did not come into effect until September 2003, after ratification by the requisite number of states (and corresponding shipping fleet tonnage). Subsequent amendments entered into force on 1 August 2005.

Annex IV applies to countries that are a party to the Annex, and all vessels operating under their flags. It generally requires ships to be equipped with either a sewage treatment plant, a sewage comminuting and disinfecting system, or a sewage holding tank. Within three miles of shore, Annex IV requires that sewage discharges be treated by a certified MSD prior to discharge. Sewage discharges made between three and 12 miles of shore must be treated by no less than maceration and chlorination, and sewage discharges beyond 12 miles from shore are unrestricted. In addition, this Annex establishes certain sewage reception facility standards and responsibilities for ports of contracting parties.

Annex IV also establishes a model International Sewage Pollution Prevention Certificate. Vessel certification requires that a vessel install (1) a sewage treatment unit that meets IMO standards (MEPC.2(VI), Recommendation on International Effluent Standards and Guidelines for Performance Tests for Sewage Treatment Plants), (2) a holding tank with an established sewage holding capacity and a visual indicator of actual capacity, and (3) a pipeline to the vessel's exterior for sewage discharge into a reception facility at port.

The United States is not a party to MARPOL Annex IV. Under Coast Guard policy, however, foreign-flagged vessels operating in the United States may use MSDs that have received a compliance test certificate under Annex IV of MARPOL. For vessels flagged in countries that are party to MARPOL Annex IV, the vessel owner and flag state have the responsibility to ensure that the vessel complies with MARPOL requirements (as well as the other safety and environmental protection requirements of international conventions). The Coast Guard’s responsibility is to verify that the vessel is in substantial compliance with the conventions, a determination that the Coast Guard makes if the treatment unit is in "good and serviceable condition." Because the majority of cruise ships are foreign-flagged, Annex IV certification remains an important aspect of cruise ship inspection activity in U.S. waters.

2.2.3 Certain Alaskan Cruise Ship Operations

On December 12, 2000, Congress enacted an omnibus appropriation that included new statutory requirements for certain cruise ship discharges occurring in Alaska (Departments of Labor, Health and Human Services, and Education, and Related Agencies Appropriations Act, 2001, Pub. L. No. 106-554, 114 Stat. 2763, enacting into law Title XIV of Division B of H.R. 5666, 114 Stat. 2763A-315, and codified at 33 U.S.C. § 1901 Note). Title XIV set discharge standards for sewage and graywater from certain cruise ships (those authorized to carry 500 or more passengers for hire) while operating in the Alexander Archipelago and the navigable waters of the United States in the State of Alaska and within the Kachemak Bay National Estuarine Research Reserve (referred to here as "Alaskan waters"). This federal law, referred to here as "Title XIV," also authorized EPA to develop revised or additional standards for discharges of sewage and graywater from cruise ships operating in Alaskan waters, if appropriate. In developing revised or additional standards, EPA must take into account the best available scientific information on the environmental effects of the regulated discharges and the availability of new technologies for wastewater treatment, and ensure that the standards are, at a minimum, consistent with all relevant State of Alaska water quality standards.

Before this law was passed, there was considerable concern about cruise ships discharging untreated sewage and graywater into areas within the Alexander Archipelago (a chain of islands in Southeast Alaska), but beyond three miles from any shore. In these areas, known as doughnut holes, the discharge of sewage was unregulated. Title XIV prohibited discharges of untreated sewage from cruise vessels and set requirements for discharges of treated sewage and graywater from cruise vessels into Alaskan waters, including the doughnut holes.

Specifically, Title XIV requires that discharges within one nautical mile of shore or discharges in any Alaskan waters when the ship is traveling under six knots meet stringent standards for fecal coliform (geometric mean of samples taken during any 30-day period does not exceed 20 fecal coliform/100ml and not more than 10% of the samples exceed 40 fecal coliforms/100ml) and chlorine (total chlorine residual does not exceed 10.0 micrograms/liter), and meet secondary treatment standards for biochemical oxygen demand, suspended solids, and pH (found at 40 CFR 133.102). Title XIV requires that discharges of treated sewage outside of one nautical mile from shore from vessels traveling at least six knots meet EPA's CWA section 312 performance standards for Type II marine sanitation devices (no more than 200 fecal coliforms per 100ml and no more than 150 milligrams total suspended solids per liter).

Title XIV requires the Coast Guard to incorporate an inspection regime into the commercial vessel examination program sufficient to verify compliance with the Act, authorizes the Coast Guard to conduct unannounced inspections and to require logbooks of all sewage and graywater discharges, and provides EPA and the Coast Guard with authority to gather information to verify compliance with the Act. Title XIV also authorizes Alaska to petition EPA to establish no-discharge zones for sewage and graywater from cruise ships.

Pursuant to Title XIV, EPA has carried out a multi-year project to determine whether revised or additional standards for sewage and graywater discharges from large cruise ships operating in Alaska are warranted under that legislation. EPA sampled wastewater from four cruise ships that operated in Alaska during the summer of 2004. The purpose of this sampling was to characterize graywater and sewage generated onboard and to evaluate the performance of various advanced sewage and graywater treatment systems. EPA also distributed a "Survey Questionnaire to Determine the Effectiveness, Costs, and Impacts of Sewage and Graywater Treatment Devices for Large Cruise Ships Operating in Alaska” to all cruise ships authorized to carry 500 or more passengers for hire that operated to Alaska in 2004. Using these sampling results, survey responses, and other relevant information, EPA is performing environmental, economic, and engineering analyses to determine whether revised or additional standards in Alaska are warranted. EPA anticipates announcing its determination and making its analyses publicly available in 2008. Much of the information and data collected for EPA’s effort under Title XIV are summarized in this report.

2.2.4 National Marine Sanctuaries Act

The National Marine Sanctuaries Act (16 U.S.C. § 1431 et seq.), as amended, established a national program to designate certain areas of marine environments as areas of special national significance that warrant heightened care. The primary purpose of the law is to protect marine resources, such as coral reefs, sunken historical vessels, or unique habitats, from degradation while facilitating public or private uses compatible with resource protection.

The Act authorizes NOAA to designate as National Marine Sanctuaries areas of the marine environment that have special aesthetic, ecological, historical, or recreational qualities, and to provide comprehensive and coordinated conservation management for such areas. The National Marine Sanctuary Program manages 13 sanctuaries and the Papahānaumokuākea Marine National Monument. Designated sanctuaries are managed according to site-specific management plans developed by NOAA that typically prohibit the discharge or deposit of most material. Discharges of graywater and treated vessel sewage, however, are sometimes allowed provided they are authorized under the Clean Water Act. In some sanctuaries the discharge of sewage is prohibited in special zones to protect fragile habitat, such as coral. The Act also provides for civil penalties for violations of its requirements or the permits issued under it.

2.3 How do cruise ships treat sewage?

As discussed above, any ship greater than 65 feet in length must use either a Type II (flow through treatment device) or Type III (holding tank) marine sanitation device (MSD). An increasing number of cruise ships are using more effective and expensive Type II MSDs, referred to as “Advanced Wastewater Treatment systems” (AWTs), to treat both sewage and graywater (generally wastewater from sinks, baths, showers, laundry, and galleys; see Section 3 for more information on graywater).

One recent estimate by the cruise industry is that roughly 40% of the International Council of Cruise Lines members’ 130 ships (which make up two-thirds of the world fleet) have installed AWTs, with 10 to 15 more systems added each year (Choi, 2007). In 2006, 23 of 28 large cruise ships that operated in Alaskan waters had AWTs in order to meet the more stringent discharge requirements in effect there (see subsection 2.2.3 above). The remainder operated traditional Type II MSDs and held the treated sewage and untreated graywater in double-bottom ballast tanks for discharge outside Alaskan waters.

This subsection provides information on the types of MSDs most often used by cruise ships: traditional Type II MSDs (2.3.1) and AWTs (2.3.2). Specifically, it discusses how these systems work and how well they remove various pollutants from the wastestream. Subsection 2.4 (below) discusses potential environmental impacts of sewage from cruise ships.

2.3.1 Traditional Type II Marine Sanitation Devices

How it works

On most cruise ships with traditional Type II MSDs, sewage is treated using biological treatment and chlorination. Some cruise ships do not treat their sewage biologically, but instead use maceration and chlorination. Of the nine large cruise ships with traditional Type II MSDs that operated in Alaskan waters in 2004, six used biological treatment and chlorination, and three used maceration and chlorination.

Biological-chlorination MSDs operate similarly to land-based biological treatment systems for municipal wastewater treatment. The treatment system typically includes aerobic biological treatment to remove biochemical oxygen demand (BOD_5) and some nutrients, clarification and filtration to remove solids, and final chlorine disinfection to destroy pathogens (see Figure 2-3). The system also may include screening to remove grit and debris. Cruise ships typically install up to four systems, allowing one or two to be placed off-line for maintenance at any one time (ADEC, 2000b).

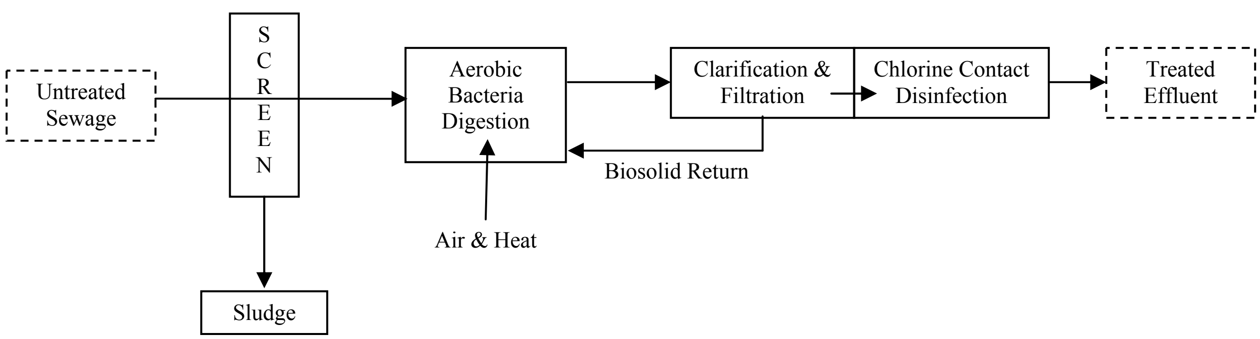

Figure 2-3. Simplified Schematic of Traditional Type II Marine Sanitation Device Using Biological Treatment and Chlorine Disinfection

Maceration-chlorination systems use screening to remove grit and debris, maceration for solids size reduction, and chlorine disinfection to oxidize and disinfect the waste. Chlorine is either added (sodium hypochlorite) or generated by mixing the sewage with sea water and then passing this solution between electrolytic cells to produce hypochlorite.

How well it works in practice

Data Collection

The primary information available on discharges from tradition Type II MSDs is from a voluntary sampling effort in Alaska in 2000 by the Alaska Cruise Ship Initiative (ADEC, 2001). These data are no longer representative of cruise ships operating in Alaska, which have mostly installed AWTs, but they may be indicative of the discharges from vessels with Type II MSDs operating in other waters. Twice during the 2000 cruise season, samples were collected from each sewage and graywater discharge port from each of the 21 large cruise ships operating in Alaska. (All except two of the sampled vessels treated sewage using traditional Type II MSDs. The other two vessels treated mixed sewage and graywater using prototype reverse osmosis Advanced Wastewater Treatment systems. Data from all 21 vessels, including the two vessels with reverse osmosis systems, are included in this summary because in most cases it was not possible to identify results from the two vessels with reverse osmosis systems.)

ACSI sampling was scheduled randomly at various ports of call on all major cruise routes in Alaska. Individual discharge samples characterized different types of wastewater depending on ship-specific discharge configurations. As a result, individual samples characterized one or more graywater sources, treated sewage, or combined graywater and treated sewage. Analytes included total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), pH, fecal coliform, total residual chlorine (TRC), free residual chlorine, and ammonia for all samples, and priority pollutants (metals, hydrocarbons, organochlorines) for one sample per ship. Samples were not taken of the influent to the treatment systems; therefore, percent removals achieved by these systems cannot be determined.

The results of this ACSI sampling are discussed in more detail below, but in summary, 43% of the samples for fecal coliform met the MSD standard of 200 fecal coliform per 100 ml, 32% of the samples for TSS met the MSD standard of 150 mg/l, and only 1 blackwater sample out of 70 samples met both the TSS and fecal coliform standards (ADEC, 2001).

The Coast Guard inspected six of the cruise ships with poor effluent samples and found that five out of the six were either operating the MSDs improperly or failing to maintain them (ADEC, 2000a).

Pathogen Indicators

Based on data collected by ACSI in 2000, the average fecal coliform concentration in traditional Type II MSD effluent was 2,040,000 MPN/100 mL (total of 92 samples, calculation used detection limits for nondetected results). The range was from nondetect (detection limit of 2) to 24,000,000 MPN/100 mL. Of the 92 samples, 51 were greater than 200 MPN/100 mL, 35 were greater than 100,000, and 22 were greater than 1,000,000. This compares to typical fecal coliform concentrations in untreated domestic wastewater of 10,000 to 100,000 MPN/100 mL (Metcalf & Eddy, 1991). Fecal coliform is the only pathogen indicator analyzed by ACSI. As mentioned above, these data are primarily for traditional Type II MSDs, but two of the 21 vessels sampled were using prototype reverse osmosis treatment systems.

Conventional Pollutants and Other Common Analytes

Table 2-1 shows ACSI sampling results for some conventional pollutants and other common analytes in MSD effluent, as well as typical concentrations in untreated domestic wastewater. These key analytes are commonly used to assess wastewater strength.

Table 2-1. Comparison of Traditional Type II MSD Effluent Concentrations to Untreated Domestic Wastewater–Conventional Pollutants and Other Common Analytes

Analyte	Average Conc. (± SE) of Cruise Ship Type II MSD Effluent[1]	Concentration in Untreated Domestic Wastewater[2]
Total Suspended Solids (mg/L)	627 (±94.3) (21 detects out of 21 samples)	100 to 350
Biochemical Oxygen Demand (5-Day) (mg/L)	133 (±15.2) (21 detects out of 21 samples)	110 to 400
Chemical Oxygen Demand (mg/L)	1,040 (±271) (3 detects out of 3 samples)	250 to 1,000
pH	90.5% of the pH samples are between 6.0 and 9.0 (21 detects out of 21 samples)	between 6.0 and 9.0
Total residual chlorine (μg/L)	1,070* (±499) (12 detects out of 18 samples)	No data

[1] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[2] Metcalf & Eddy, 1991.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Metals

ACSI sampled for 13 priority pollutant metal analytes, of which 8 were detected in greater than 10% of the Type II MSD effluent samples (less frequent detection of analytes is considered not representative of the wastestream; in fact, of the metal analytes detected in any samples, none were detected in fewer than 10% of the samples) (see Table 2-2). Copper and zinc were detected in the greatest amounts.

Table 2-2. Traditional Type II MSD Effluent Concentrations–Metals

Analyte	Average Conc. (± SE) of Cruise Ship Type II MSD Effluent[1]
Cadmium (Total) (µg/L)	0.0624* (±0.0205) (3 detects out of 24 samples)
Chromium (Total) (µg/L)	5.99* (±2.50) (8 detects out of 24 samples)
Copper (Total) (µg/L)	954* (±398) (19 detects out of 24 samples)
Lead (Total) (µg/L)	6.94* (±2.72) (7 detects out of 24 samples)
Mercury (Total) (µg/L)	0.206* (±0.0574) (8 detects out of 22 samples)
Nickel (Total) (µg/L)	15.8* (±7.34) (5 detects out of 22 samples)
Silver (Total) (µg/L)	0.527* (±0.166) (9 detects out of 22 samples)
Zinc (Total) (µg/L)	514* (±97.3) (19 detects out of 22 samples)

[1] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Volatile and Semivolatile Organics

ACSI sampled for almost 140 volatile and semivolatile organic analytes. Of these, 16 were detected in at least 10% of effluent samples (less frequent detection of analytes is considered not representative of cruise ship effluent; analytes that were detected in fewer than 10% of samples were detected in only one or two samples). Table 2-3 presents the average volatile and semivolatile organic concentrations in Type II effluent for these 16 analytes. Some of the analytes in this table with the highest concentrations are chlorine byproducts, likely generated by sewage chlorination.

Table 2-3. Traditional Type II MSD Effluent Concentrations–Volatile and Semivolatile Organics

Analyte	Average Conc. (± SE) of Cruise Ship Type II MSD Effluent[1]
1,2-Dichloroethane (µg/L)	0.879* (±0.0666) (8 detects out of 21 samples)
1,4-Dichlorobenzene (µg/L)	17.4* (±16.6) (4 detects out of 21 samples)
Bis(2-ethylhexyl) phthalate (µg/L)	3.45* (±0.837) (16 detects out of 21 samples)
Bromodichloromethane (µg/L) [2]	33.7* (±12.7) (14 detects out of 21 samples)
Bromoform (µg/L) [2]	43.6* (±21.9) (13 detects out of 22 samples)
Carbon tetrachloride (µg/L)	1.96* (±1.12) (5 detects out of 24 samples)
Chloroform (µg/L) [2]	111* (±63.3) (21 detects out of 24 samples)
Chloromethane (µg/L)	24.4* (±12.9) (5 detects out of 22 samples)
Dibromochloromethane (µg/L) [2]	27.4* (±12.0) (11 detects out of 24 samples)
Diethyl phthalate (µg/L)	1.00* (±0.204) (5 detects out of 24 samples)
Di-n-butyl phthalate (µg/L)	2.65* (±0.445) (13 detects out of 24 samples)
Ethylbenzene (µg/L)	0.624* (±0.181) (5 detects out of 24 samples)
Methylene chloride (µg/L)	4.02* (±1.81) (3 detects out of 22 samples)
Phenol (µg/L)	26.5* (±13.5) (7 detects out of 22 samples)

Analyte	Average Conc. (± SE) of Cruise Ship Type II MSD Effluent[1]
Tetrachloroethylene (µg/L)	12.5* (±10.5) (3 detects out of 22 samples)
Toluene (µg/L)	0.620* (±0.0771) (5 detects out of 22 samples)

[1] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[2] Trihalomethanes are water system disinfection byproducts.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Nutrients

Table 2-4 shows average ammonia concentration in effluent from traditional Type II MSDs, as well as typical concentrations in untreated domestic wastewater.

Table 2-4. Comparison of Traditional Type II MSD Effluent Concentrations to Untreated Domestic Wastewater–Ammonia

Analyte	Average Conc. (± SE) of Cruise Ship Traditional Type II MSD Effluent[1]	Concentration in Untreated Domestic Wastewater[2]
Ammonia as Nitrogen (mg/L)	145 (±36.7) (21 detects out of 21 samples)	12 to 50

[1] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[2] Metcalf & Eddy, 1991.

2.3.2 Advanced Wastewater Treatment Systems

How it works

On some cruise vessels, especially many of those traveling to Alaska (see subsection 2.2.3 above), sewage and often graywater are treated using Advanced Wastewater Treatment systems (AWTs). AWTs generally provide improved screening, biological treatment, solids separation (using filtration or flotation), disinfection (using ultraviolet light), and sludge processing as compared to traditional Type II MSDs. The AWTs currently used by cruise ships operating in Alaskan waters are discussed in this subsection.

Hamworthy's Membrane Bioreactor (MBR) system uses aerobic biological treatment followed by ultrafiltration and ultraviolet (UV) disinfection. One example of this system is in operation on the Princess Cruises vessel Island Princess. On this vessel, the Hamworthy MBR system treats wastewater from accommodations and sewage. Wastewater is first treated in screen presses to remove paper and other coarse solids. Next, the wastewater enters a two-stage bioreactor, where bacteria digest the organic matter in the waste. Following biological treatment, the wastewater is filtered through tubular ultrafiltration membranes to remove particulate matter and biological mass, which are returned to the bioreactors. In the final stage of treatment, the wastewater undergoes UV disinfection. See EPA, 2006c, for more detailed information on this system.

ROCHEM's ROCHEM LPRO and ROCHEM Bio-Filt® system treats high concentration and low concentration wastestreams with different processes. One example of this system is in operation on the Holland America Line vessel Oosterdam. On this vessel, the ROCHEM LPRO part of the system treats wastewater from laundry and accommodations (low concentration wastestreams) while the ROCHEM Bio-Filt® treats wastewater from galley and sewage, as well as the membrane concentrate from the ROCHEM LPRO system (high concentration wastestreams). The ROCHEM LPRO system uses screens to remove fibers and hair, reverse osmosis membranes to remove particulates and dissolved solids, and UV disinfection to destroy pathogens. The ROCHEM Bio-Filt® system uses vibratory screens to remove coarse solids, bioreactors to biologically oxidize the waste, ultrafiltration membranes to remove particulate matter and biological mass (which are returned to the bioreactors), and UV disinfection to destroy pathogens. See EPA, 2006d, for more detailed information on this system.

The Zenon ZeeWeed® MBR system uses aerobic biological oxidation followed by ultrafiltration and UV disinfection. One example of this system is in operation on the Holland America Line vessel Veendam. On this vessel, graywater from the laundry, galley, accommodations, and food pulper combines with sewage and flows through two coarse screens into a collection tank. From the collection tank, the wastewater is pumped to an aerated bioreactor. After the bioreactor, the wastewater flows through the proprietary ZeeWeed® hollow-fiber ultrafiltration membrane system under a vacuum. In the final stage of treatment, the combined wastewater from the membranes undergoes UV disinfection. The Zenon system is the only system that EPA sampled that treats all graywater and sewage sources. See EPA, 2006a, for more detailed information on this system.

The Scanship treatment system uses aerobic biological oxidation followed by dissolved air flotation and UV disinfection. One example of the Scanship system is in operation on the Norwegian Cruise Line vessel Star. On this vessel, sewage and graywater from the galley, accommodations, and laundry combine in one graywater and sewage holding tank. The combined wastewater is pumped through a coarse drum filter and then through two separate aerated bioreactors. Each bioreactor contains free-floating plastic beads to support biological growth, eliminating the need for recycled biological mass. After aeration, the wastewater is pumped to two dissolved air flotation (DAF) units to separate solids. From the DAF units, the wastewater is pumped to polishing screen filters. In the final stage of treatment, the wastewater undergoes UV disinfection for destruction of bacteria and viruses. See EPA, 2006b, for more detailed information on this system.

The Hydroxyl CleanSea® system uses aerobic biological oxidation followed by dissolved air flotation and ultraviolet (UV) disinfection. Sewage and graywater are combined and pumped to a fine wedgewire screen for coarse solids removal. Next, the wastewater enters the ACTIVECELL™ biological reactors where free-floating plastic beads support biological growth without the need for recycled biological mass. The wastewater then enters the ACTIVEFLOAT™ dissolved air flotation units for solids separation. Final treatment steps include polishing filters and UV disinfection (Hydroxyl Systems, 2007). None of the ships that EPA sampled in 2004 and 2005 used the Hydroxyl CleanSea® system. Through 2007, EPA is not aware of any ships using the Hydroxyl system that have been approved for continuous discharge in Alaskan waters.

How well it works in practice

In 2004 and 2005, EPA sampled wastewater from four cruise ships that operated in Alaska to characterize graywater and sewage generated onboard and to evaluate the performance of the Zenon, Hamworthy, Scanship, and ROCHEM AWTs (see EPA, 2006 a-e). EPA also has evaluated cruise ship compliance monitoring data for AWT effluent provided by the Alaska Department of Environmental Conservation (ADEC) and the Coast Guard for 2003 through 2005, and self-monitoring data for AWT effluent submitted by the cruise industry in response to EPA's 2004 cruise ship survey.

These sampling results, which are described in greater detail below, indicate that AWTs are very effective in removing pathogens, oxygen demanding substances, suspended solids, oil and grease, and particulate metals. AWTs remove some of the dissolved metals (37 to 50%). Most volatile and semi-volatile organics are removed to levels below detection limits, while others show moderate removal. AWTs achieve moderate nutrient removals, likely resulting from nutrient uptake by the microorganisms in the bioreactors.

Data Collection

EPA Sampling: In 2004 and 2005, EPA analyzed the effluent from Zenon, Hamworthy, Scanship, and ROCHEM AWTs (see EPA, 2006 a-e) for over 400 analytes, including pathogen indicators, suspended and dissolved solids, biochemical oxygen demand, oil and grease, dissolved and total metals, organics, and nutrients.

ADEC/Coast Guard Sampling: AWT effluent data are collected through compliance monitoring required by state and federal law for all cruise ships that discharge in Alaskan waters. Since 2001, Alaska state law requires a minimum of two discharge samples per year for large cruise ships. Both samples are analyzed for fecal coliform and other common pollutants, and one sample is also analyzed for priority pollutants. This program is managed by the Alaska Department of Environmental Conservation (ADEC). Additionally, the federal law entitled "Certain Alaska Cruise Ship Operations" requires compliance monitoring of discharges from vessels approved for continuous discharge in Alaskan waters (see subsection 2.2.3 above). Sampling frequency and analytes are at the discretion of the Captain of the Port (COTP). The COTP requires discharge sampling twice per month for fecal coliform and other common pollutants. Although AWT compliance monitoring data are available beginning in 2001, EPA is using data collected beginning in 2003 as representative of AWT discharges due to sampling constraints prior to 2003.

Data from EPA's 2004 Cruise Ship Survey: EPA's 2004 cruise ship survey asked cruise ships operating in Alaska in 2004 to submit any additional monitoring data collected in Alaska that was not previously provided to EPA through ADEC or the Coast Guard. EPA received a small amount of additional AWT effluent monitoring data from six ships in response to this request (monitoring is seldom performed other than for compliance). These data comprise less than 2% of the data summarized below.

To date, all available AWT effluent monitoring data are from four AWT systems: Hamworthy Membrane Bioreactor (MBR); ROCHEM LPRO and ROCHEM Bio-Filt®; Zenon ZeeWeed® MBR; and Scanship. This is because these were the only AWT systems certified for continuous discharge in Alaska through 2005. All four of these AWTs treat sewage and at least some graywater sources. Therefore, these results apply to graywater treatment as well.

Pathogen Indicators

EPA analyzed both the influent and the effluent from AWTs (mixed graywater and sewage), as well as the influent to UV disinfection, for the pathogen indicators fecal coliform, enterococci, and *E. coli*. Fecal coliform were analyzed for comparison to the MSD and Title XIV standards. EPA chose to sample for *E. coli* and enterococci because epidemiological studies suggest a positive relationship between high concentrations of *E. coli* and enterococci in ambient waters and incidents of gastrointestinal illnesses associated with swimming (EPA, 1984b, and EPA, 1983).

ADEC/Coast Guard analyzed for fecal coliform to assess compliance with the fecal coliform discharge standards. EPA also received some fecal coliform data in response to the survey.

Sampling data indicate that AWTs remove pathogen indicators to levels below detection (>99% removal) (see Table 2-5). Over 96% of pathogen indicators were removed by the bioreactors and solids separation units; any remaining pathogen indicators were generally removed by UV disinfection to levels below detection (overall system efficiency >99%). When detected, pathogen indicators were generally at levels close to the detection limit.

Table 2-5. AWT Effluent Concentrations and Removals–Pathogen Indicators

Analyte	Unit	Average Concentration in Cruise Ship AWT Influent[1]	Average Concentration after bioreactors but before UV Disinfection[1]	Average Concentration in Cruise Ship AWT Effluent[2]	Overall AWT Percent Removal[1]
Fecal Coliform	CFU / 100 mL	103,000,000* (61 detects out of 62 samples)	25,500# (39 detects out of 56 samples)	14.5* (26 detects out of 285 samples)	>99
	MPN / 100 mL			10.1* (47 detects out of 320 samples)	
E. coli	MPN / 100 mL	12,700,000 (63 detects out of 63 samples)	727* (38 detects out of 55 samples)	1.98* (6 detects out of 59 samples)	>99
Enterococci	MPN / 100 mL	4,940,000* (63 detects out of 64 samples)	97.4# (33 detects out of 54 samples)	1.28* (9 detects out of 58 samples)	>99

[1] Based on data collected by EPA in 2004.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Average includes at least one nondetect value (calculation uses detection limits for nondetected results) and at least one result flagged by the laboratory as not diluted sufficiently.
The “>” symbol indicates a minimum level of removal.

Conventional Pollutants and Other Common Analytes

Table 2-6 presents AWT effluent sampling data for various common analytes including conventional pollutants (other than fecal coliform), chlorine, and temperature. Each of the three data sources (sampling by ADEC/Coast Guard from 2003 to 2005; sampling by EPA in 2004; sampling data collected through EPA’s 2004 cruise ship survey) includes data for some of these analytes; however, not all sources analyzed for all of them. At a minimum, all three data sources analyzed the key analytes commonly used to assess wastewater strength: biochemical oxygen demand, chemical oxygen demand, and total suspended solids.

The AWTs remove almost all biochemical oxygen demand, chemical oxygen demand, and total organic carbon. The systems also remove settleable residue and total suspended solids to levels at or near detection.

Table 2-6. AWT Effluent Concentrations and Removals–Conventional Pollutants and Other Common Analytes

Analyte	Unit	Average Concentration in Cruise Ship AWT Influent[1]	Average Conc. (± SE) in Cruise Ship AWT Effluent[2]	Percent Removal[1]
Alkalinity	mg/L CaCO	325 (25 detects out of 25 samples)	178 (±9.61) (127 detects out of 127 samples)	32 to 78
Biochemical Oxygen Demand (5-day)	mg/L	526 (24 detects out of 24 samples)	7.99* (±0.798) (358 detects out of 568 samples)	>99
Chemical Oxygen Demand	mg/L	1,140 (50 detects out of 50 samples)	69.4* (±4.03) (139 detects out of 147 samples)	>93 to 97
Chloride	µg/L	294 (25 detects out of 25 samples)	389 (±93.9) (20 detects out of 20 samples)	NC to 16
Conductivity	umhos/cm		1,450 (±268) (105 detects out of 105 samples)	
Hardness	mg/L	135 (25 detects out of 25 samples)	120 (±30.5) (20 detects out of 20 samples)	
Hexane extractable material (HEM)	mg/L	95.6 (25 detects out of 25 samples)	5.74* (±0.154) (13 detects out of 127 samples)	>91 to >96
pH	SU		99.5% of samples within range of 6.0 to 9.0 (921 detects out of 921 samples)	
Residual Chlorine, Free	mg/L		0.249* (±0.0993) (22 detects out of 511 samples)	
Residual Chlorine, Total	mg/L		0.338* (±0.129) (41 detects out of 547 samples)	
Salinity	ppt		1.93* (±0.606) (76 detects out of 77 samples)	
Silica Gel Treated Hexane Extractable Material (SGT-HEM)	mg/L	22.1* (17 detects out of 25 samples)	ND (0 detects out of 20 samples)	NC to >92
Temperature	°C		31.3 (±0.198)	

Analyte	Unit	Average Concentration in Cruise Ship AWT Influent[1]	Average Conc. (± SE) in Cruise Ship AWT Effluent[2]	Percent Removal[1]
			(403 detects out of 403 samples)	
Total Dissolved Solids	mg/L	776 (25 detects out of 25 samples)	819 (±169) (20 detects out of 20 samples)	NC to 34
Total Organic Carbon	mg/L	169 (25 detects out of 25 samples)	19.0* (±1.20) (123 detects out of 127 samples)	86 to 94
Total Settleable Solids	mL/L	33.5* (23 detects out of 24 samples)	0.141* (±0.0385) (3 detects out of 83 samples)	>99
Total Suspended Solids	mg/L	545 (50 detects out of 50 samples)	4.49* (±0.193) (73 detects out of 587 samples)	>99
Turbidity	NTU		2.31* (±0.894) (62 detects out of 76 samples)	

1 Based on data collected by EPA in 2004 and 2005.
2 Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004 and 2005; and data collected through EPA's 2004 cruise ship survey.
"NC" indicates that percent removal not calculated because the effluent concentration was greater than the influent concentration or the analyte was not detected in the influent samples from one or more sampled ships.
"ND" indicates not detected.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.
The ">" symbol indicates a minimum level of removal.

Metals

EPA sampled for 54 total and dissolved metal analytes. ADEC/Coast Guard analyzed for priority pollutant metal analytes (total and dissolved). Survey respondents provided some priority pollutant metals data.

Table 2-7 presents AWT effluent sampling data for priority pollutant metals that were detected in greater than 10% of influent and/or effluent samples (less frequent detection of analytes is considered not representative of the wastestream).

Metals are present in both particulate and dissolved forms in the influents to the treatment systems. Metals in the effluent are predominantly in the dissolved form. This suggests that the treatment systems are very efficient in removing particulate metals, as would be expected for membrane and dissolved air flotation solids separation systems (and as supported by nearly complete removal of settleable solids and TSS). Sampling results indicate that AWTs remove 37 to 50% of dissolved metals on average.

Table 2-7. AWT Effluent Concentrations and Removals–Metals

Analyte[1]	Unit	Average Concentration in Cruise Ship AWT Influent[2]	Average Conc. (± SE) in Cruise Ship AWT Effluent[3]	Percent Removal[2]
Antimony, Total	µg/L	ND	2.38* (±0.219) (15 detects out of 71 samples)	
Antimony, Dissolved	µg/L	4.0* (1 detect out of 25 samples)	2.38* (±0.219) (11 detects out of 71 samples)	
Arsenic, Total	µg/L	2.2* (3 detects out of 25 samples)	2.51* (±0.203) (22 detects out of 71 samples)	NC to >3.8
Arsenic, Dissolved	µg/L	ND	2.28* (±0.166) (19 detects out of 71 samples)	NC
Cadmium, Total	µg/L	0.45* (13 detects out of 25 samples)	0.824* (±0.147) (2 detects out of 71 samples)	>0.6 to 78
Chromium, Total	µg/L	6.64* (24 detects out of 25 samples)	4.29* (±0.992) (27 detects out of 71 samples)	>44 to 95
Chromium, Dissolved	µg/L	1.51* (15 detects out of 25 samples)	3.71* (±0.786) (28 detects out of 71 samples)	49 to 67
Copper, Total	µg/L	519 (25 detects out of 25 samples)	16.6* (±2.74) (69 detects out of 71 samples)	96 to 98
Copper, Dissolved	µg/L	81.5 (25 detects out of 25 samples)	13.7* (±2.40) (65 detects out of 71 samples)	62 to 94
Lead, Total	µg/L	9.25* (22 detects out of 25 samples)	1.50* (±0.135) (27 detects out of 71 samples)	42 to >84
Lead, Dissolved	µg/L	2.36* (13 detects out of 25 samples)	1.35* (±0.138) (20 detects out of 71 samples)	NC to >30
Mercury, Total[4]	µg/L	0.310* (21 detects out of 25 samples)	0.165* (±0.00895) (10 detects out of 70 samples)	60 to 92
Mercury, Dissolved[4]	µg/L	0.120* (10 detects out of 25 samples)	0.176* (±0.00941) (10 detects out of 68 samples)	NC to 32
Nickel, Total	µg/L	22.4 (25 detects out of 25 samples)	13.6* (±2.01) (70 detects out of 71 samples)	NC to 48
Nickel, Dissolved	µg/L	17.1 (25 detects out of 25 samples)	13.3* (±1.96) (69 detects out of 71 samples)	NC to 32
Selenium, Total	µg/L	9.68* (13 detects out of 25 samples)	5.86* (±1.20) (33 detects out of 71 samples)	12 to 38
Selenium, Dissolved	µg/L	8.39* (10 detects out of 25 samples)	6.14* (±1.48) (29 detects out of 71 samples)	NC to 24
Silver, Total	µg/L	1.70* (14 detects out of 25 samples)	1.15* (±0.109) (17 detects out of 71 samples)	>0.5 to >74
Silver, Dissolved	µg/L	ND	1.00* (±0.0844) (10 detects out of 71 samples)	NC
Thallium, Total	µg/L	0.860* (2 detects out of 25 samples)	1.02* (±0.194) (11 detects out of 71 samples)	NC to 3.2
Zinc, Total	µg/L	986 (25 detects out of 25 samples)	198* (±22.7) (69 detects out of 71 samples)	NC to 86
Zinc, Dissolved	µg/L	209 (25 detects out of 25 samples)	185* (±21.4) (70 detects out of 71 samples)	NC

[1] Priority pollutant metal analytes detected in at least 10% of AWT influent and/or effluent samples.
[2] Based on data collected by EPA in 2004.
[3] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
[4] Because it was not possible to incorporate "clean" sampling and analysis methodologies for mercury when sampling onboard ships, there is no way for EPA to determine whether mercury reported here is present in AWT influent and effluent or if the mercury was the result of contamination from nearby metal or sources of airborne contamination.
"NC" indicates that percent removal not calculated because the effluent concentration was greater than the influent concentration or the analyte was not detected in the influent samples from one or more sampled ships.
"ND" indicates not detected.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Volatile and Semivolatile Organics

EPA's volatile and semivolatile organics analyte list includes 84 volatile and semivolatile organics and focuses primarily on priority pollutants. ADEC/Coast Guard's volatile and semivolatile organic analytes include approximately 135 organics (including all 84 analytes on EPA's list) and is nearly identical to that analyzed for during the 2000 voluntary sampling program. Survey respondents also provided some organics data.

Table 2-8 presents AWT effluent sampling data for priority pollutant volatile and semivolatile organics that were detected in greater than 10% of influent and/or effluent samples (less frequent detection of analytes is considered not representative of the wastestream). AWTs generally remove volatile and semivolatile organics to below detection limits.

Table 2-8. AWT Effluent Concentrations and Removals–Volatile and Semivolatile Organics

Analyte[1]	Unit	Average Concentration in Cruise Ship AWT Influent[2]	Average Conc. (± SE) in Cruise Ship AWT Effluent[3]	Percent Removal[2]
2,4-Dichlorophenol	µg/L	ND	8.48* (±1.08) (8 detects out of 71 samples)	
Bis(2-ethylhexyl) phthalate	µg/L	46.1* (21 detects out of 25 samples)	6.66* (±0.721) (2 detects out of 71 samples)	>37 to >90
Chloroform	µg/L	10.1* (5 detects out of 25 samples)	3.74* (±0.351) (27 detects out of 71 samples)	NC to >67
Diethyl phthalate	µg/L	13.1* (8 detects out of 25 samples)	8.57* (±1.06) (7 detects out of 71 samples)	NC to >51
Di-n-butyl phthalate	µg/L	ND	8.32* (±1.07) (8 detects out of 71 samples)	
Phenol	µg/L	75.0* (24 detects out of 25 samples)	20.7* (±3.00) (25 detects out of 71 samples)	25 to 45
Tetrachloroethylene	µg/L	255* (8 detects out of 25 samples)	5.59* (±1.05) (10 detects out of 71 samples)	>44 to 97
Toluene	µg/L	7.67* (5 detects out of 25 samples)	3.44* (±0.346) (10 detects out of 71 samples)	>1.4 to >17
Trichloroethene	µg/L	15.1* (5 detects out of 25 samples)	3.54* (±0.337) (1 detects out of 71 samples)	>75

[1] Priority pollutant volatile and semivolatile organics detected in at least 10% of AWT influent and/or effluent samples.
[2] Based on data collected by EPA in 2004.
[3] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
"NC" indicates that percent removal not calculated because the effluent concentration was greater than the influent concentration or the analyte was not detected in the influent samples from one or more sampled ships.
"ND" indicates not detected.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.
The ">" symbol indicates a minimum level of removal.

Nutrients

EPA sampled for nutrients in 2004 and found that some of the 2004 results for nitrogen compounds were anomalous. Therefore, EPA performed additional nutrient sampling in 2005 onboard the same four cruise vessels. ADEC/Coast Guard also monitor nutrients, and survey respondents provided some nutrient data.

Table 2-9 presents AWT effluent sampling data for nutrients. AWTs reduce ammonia, total Kjeldahl nitrogen, and total phosphorus by moderate amounts. Nitrate/nitrite levels were low and remained relatively unchanged by treatment. Nitrogen and phosphorus are likely taken up by microorganisms in the bioreactor and removed from the system in the waste sludge. It is unlikely that ammonia is removed by nitrification, as nitrification would have resulted in an increase in nitrate/nitrite concentration, but these levels remained relatively unchanged.

Table 2-9. AWT Effluent Concentrations and Removals–Nutrients

Analyte	Unit	Average Concentration in Cruise Ship AWT Influent[1]	Average Conc. (± SE) in Cruise Ship AWT Effluent[2]	Percent Removal[1]
Ammonia As Nitrogen	mg/L	78.6 (35 detects out of 35 samples)	36.6* (±5.50) (136 detects out of 138 samples)	58 to 74
Nitrate/Nitrite as Nitrogen	mg/L	0.325* (26 detects out of 50 samples)	3.32* (±0.653) (66 detects out of 152 samples)	NC
Total Kjeldahl Nitrogen	mg/L	111 (50 detects out of 50 samples)	32.5* (±3.27) (169 detects out of 170 samples)	70 to 76
Total Phosphorus	mg/L	18.1 (25 detects out of 25 samples)	5.05* (±0.460) (146 detects out of 154 samples)	41 to 98

[1] Based on data collected by EPA in 2004 and 2005.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004 and 2005; and data collected through EPA's 2004 cruise ship survey.
"NC" indicates that percent removal not calculated because the effluent concentration was greater than the influent concentration or the analyte was not detected in the influent samples from one or more sampled ships.
"ND" indicates not detected.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Pesticides

EPA analyzed for 121 organohalide and organophosphorus pesticides in AWT influent (pesticides were not analyzed for in AWT effluent). Simazine was the only pesticide detected (concentration of 0.96 µg/L in one sample). EPA lists simazine as a General Use Pesticide (GUP) that has been used to control broad-leaved weeds and annual grasses in fields, berry fruit, and vegetables. Simazine is classified by EPA to be slightly toxic to practically non-toxic. In the past, simazine has been used to control algae in swimming pools, hot tubs, and whirlpools. (Extoxnet, 1996).

ADEC also analyzed for organophosphorus pesticides in AWT effluent in 2003. None were detected.

2.3.3 Sewage Sludge

<u>Waste Sludge</u>

In addition to the treated sewage discharge generated by cruise ships, waste sludge (excess biological mass from the bioreactors) is generated in varying amounts by all vessels that use biological treatment, including traditional Type II MSDs and AWTs. Waste sludge contains organic material, often with high concentrations of bacteria and viruses, unless treated further.

In biological treatment, microorganisms (e.g., bacteria) consume the biological matter in sewage, which produces biological mass (e.g., more bacteria). The biological mass is then separated from the treated effluent using a solids separation step such as clarification and/or filtration. A portion or all of the biological mass is recycled to the bioreactors to treat additional sewage.

Of the six large cruise ships with traditional biological Type II MSDs that operated in Alaskan waters in 2004, all recycle all of their separated biological mass to the bioreactors. This means that excess biological mass typically exits these systems entrained in the treated effluent. (Treated effluent is disinfected prior to discharge to destroy pathogens.) However, for three of the six systems, excess biological mass also accumulates in the bioreactors to unacceptable levels over time. Once or twice per month, these systems are “desludged” by removing a portion of the contents of the bioreactors. According to responses to EPA’s 2004 cruise ship survey, this waste sludge is discharged without treatment outside 12 nautical miles (nm) from shore. EPA has no sampling data for waste sludge from traditional Type II MSDs.

In AWTs, improved biological treatment results in the generation of large amounts of biological mass, while improved solids separation does not allow for the entrainment of biological mass in the treated effluent. Biological mass is recycled to the bioreactors; however, excess biological mass is removed from the AWT bioreactors on a daily or weekly basis. On all four ships sampled by EPA in 2004 and 2005, excess sludge is pumped to a double-bottom holding tank for discharge without treatment outside 12 nm from shore. The volume of sludge discharged by these four ships ranged from 370 to 6,600 gallons/day.

EPA collected one-time grab samples of waste sludge from three of the four vessels sampled in 2004 (see Table 2-10). Most of the analytes detected in the sludge also were detected in the influent to treatment. For many analytes, concentrations in the sludge exceeded those in the influent to treatment, suggesting that these analytes accumulate in the system until removed in the waste sludge stream. In particular, there were elevated metals concentrations in the waste sludge. This is expected as the AWTs are highly efficient in removing particulate metals from the effluent and retaining them in the bioreactors.

Table 2-10. AWT Sludge Concentrations for Selected Analytes

Analyte	Unit	Average Concentration in Cruise Ship AWT Influent[1]	Average Concentration in Cruise Ship AWT Waste Sludge[1]	Average Concentration in Cruise Ship AWT Screening Solids[1]
Conventional Pollutants				
Biochemical Oxygen Demand (5-Day)	mg/L	526 (24 detects out of 24 samples)	3,870 (1 detect out of 1 sample)	6,610 (1 detect out of 1 sample)
Chemical Oxygen Demand	mg/L	1,140 (50 detects out of 50 samples)	9,840 (3 detects out of 3 samples)	46,200 (3 detects out of 3 samples)
Metals				
Chromium, Total	µg/L	6.64* (24 detects out of 25 samples)	200 (3 detects out of 3 samples)	565 (3 detects out of 3 samples)
Copper, Total	µg/L	519 (25 detects out of 25 samples)	10,800 (3 detects out of 3 samples)	22,700 (3 detects out of 3 samples)
Lead, Total	µg/L	9.25* (22 detects out of 25 samples)	177 (3 detects out of 3 samples)	49.9* (2 detects out of 3 samples)
Nickel, Total	µg/L	22.4 (25 detects out of 25 samples)	245 (3 detects out of 3 samples)	537 (3 detects out of 3 samples)
Zinc, Total	µg/L	986 (25 detects out of 25 samples)	19,400 (3 detects out of 3 samples)	33,600 (3 detects out of 3 samples)
Volatile and Semivolatile Organics				
Bis (2-ethylhexyl) phthalate	µg/L	46.1* (21 detects out of 25 samples)	40.0 (2 detects out of 2 samples)	6,250* (2 detects out of 3 samples)
Phenol	µg/L	75.0* (24 detects out of 25 samples)	628 (2 detects out of 2 samples)	563* (2 detects out of 3 samples)
Tetrachloroethylene	µg/L	255* (8 detects out of 25 samples)	5.83* (2 detects out of 3 samples)	6.19* (2 detects out of 3 samples)
Trichloroethene	µg/L	15.1* (5 detects out of 25 samples)	3.74* (1 detect out of 3 samples)	ND (0 detects out of 3 samples)
Nutrients				
Ammonia as Nitrogen	mg/L	78.6 (35 detects out of 35 samples)	58.2 (2 detects out of 2 samples)	170 (2 detects out of 2 samples)
Total Kjeldahl Nitrogen	mg/L	111 (50 detects out of 50 samples)	1,030 (3 detects out of 3 samples)	740 (3 detects out of 3 samples)
Nitrate/Nitrite as Nitrogen	mg/L	0.325* (26 detects out of 50 samples)	3.51* (2 detects out of 3 samples)	1.24* (2 detects out of 3 samples)
Total Phosphorus	mg/L	18.1 (25 detects out of 25 samples)	173 (3 detects out of 3 samples)	341 (3 detects out of 3 samples)

[1] Based on data collected by EPA in 2004.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Screening Solids

Most sewage treatment systems use coarse screens or presses to remove paper and other coarse solids from sewage. Depending on the specific type of screening technology used, the resulting screening solids waste varies in water content. For the four ships that EPA sampled in 2004 and 2005, two generated relatively dry screening solids and incinerated them onboard. The other two ships generated relatively wet screening solids. One of these ships disposed of the solids on shore. The other stored the solids in double-bottom holding tanks for discharge without treatment outside 12 nm from shore (50 gallons/day of screening solids). EPA collected one-time grab samples of screening solids from three of the four vessels sampled in 2004 (see Table 2-10).

2.3.4 Cruise Industry Practice

Cruise Lines International Association (CLIA) member lines have agreed to incorporate various standards for waste stream management into their Safety Management Systems (see Section 1.3). CLIA members have agreed that all sewage will be processed through a marine sanitation device (MSD), certified in accordance with U.S. or international regulations, prior to discharge (CLIA, 2006). For ships that do not have Advanced Wastewater Treatment systems traveling regularly on itineraries beyond territorial coastal waters, discharge will take place only when the ship is more than four miles from shore and when the ship is traveling at a speed of not less than six knots (for vessels operating under sail, or a combination of sail and motor propulsion, the speed shall not be less than four knots). For vessels whose itineraries are fully within US territorial waters, discharge shall comply fully with U.S. and individual state legislation and regulations.

2.4 What are the potential environmental impacts associated with sewage from cruise ships?

In order to evaluate the potential environmental impacts of sewage waste streams from cruise ships, EPA compared the effluent from traditional Type II Marine Sanitation Devices (MSDs) and Advanced Wastewater Treatment systems (AWTs) discussed in subsection 2.3 (above) to (1) current wastewater discharge standards for ships and land-based sewage treatment plants and (2) EPA's National Recommended Water Quality Criteria.

2.4.1 Comparison to wastewater discharge standards

Table 2-11 shows the comparison of average effluent analyte concentrations from traditional Type II MSDs and from AWTs to:

- EPA's standards for discharges from Type II MSDs on vessels;
- EPA's standards for secondary treatment of sewage from land-based sewage treatment plants; and
- Alaska cruise ship discharge standards under "Certain Alaska Cruise Ship Operations" (also referred to as "Title XIV").

Traditional Type II MSD effluent concentrations exceeded the EPA standards for discharges from Type II MSDs (see Table 2-11). In addition, traditional Type II MSD effluent concentrations exceeded most wastewater discharge standards under Title XIV for continuous discharge and for secondary treatment from land-based sewage treatment plants. (Traditional Type II MSD effluent concentrations are not required to meet, nor are the devices designed to meet, the Title XIV continuous discharge standards or the secondary treatment discharge standards.)

In contrast to traditional Type II MSD effluent, the average effluent concentrations from AWTs are lower than all of the discharge standards presented in Table 2-11, with the exception of total residual chlorine. Chlorination is used to disinfect potable water produced underway or bunkered in port. In 2003 through 2005, many cruise vessels in Alaska converted from chlorine disinfection of treated sewage and graywater to ultraviolet light (UV) disinfection methods during treatment system upgrades from traditional Type II MSDs to AWT systems. The switch to UV disinfection resulted in a decline in the frequency and magnitude of detected total residual chlorine in cruise effluent from AWTs. Based on the change in disinfection methods for AWTs, the likely source for occasional detection of total residual chlorine in AWT effluent is residual chlorine in potable water.

Another factor contributing to the exceedance of the total residual chlorine standard is the difference between the total residual chlorine discharge standard of 10 µg/L and the minimum detection limit reported by most analytical labs of 100 µg/L. The average concentrations presented in Table 2-11 are calculated using the detection limit for samples where chlorine is not detected. Therefore, although total residual chlorine was detected in only 41 of 547 samples, the average is weighted higher due to the use of the detection limit (which is high relative to the standard) for nondetect samples. Alaska Department of Environmental Conservation (ADEC) uses the 100 µg/L minimum detection level as the compliance evaluation level for total residual chlorine. Therefore, cruise ships reporting nondetect values with a detection limit of 100 µg/L are considered in compliance with the Title XIV continuous discharge standards. Based on this evaluation criterion, effluent concentrations from AWT seldom exceed the minimum detection level.

Table 2-11. Comparison of AWT and Traditional Type II MSD Effluent to Wastewater Discharge Standards

Analyte	Average Concentration in AWT Effluent[1]	Average Concentration in Traditional Type II MSD Effluent[2]	Performance Standards for Type II MSDs (33 CFR Part 159 Subpart C)	Secondary Treatment Discharge Standards for Sewage from Land-based Sewage Treatment Plants (40 CFR 133.102)	Title XIV Standard for Continuous Discharge in Alaskan waters (33 CFR Part 159 Subpart E)
Fecal coliform (fecal coliform/ 100 mL)	14.5*	2,040,000* MPN / 100 mL	<200		<20[3]
Total residual chlorine (µg/L)	338*	1,070*			<10

Analyte	Average Concentration in AWT Effluent[1]	Average Concentration in Traditional Type II MSD Effluent[2]	Performance Standards for Type II MSDs (33 CFR Part 159 Subpart C)	Secondary Treatment Discharge Standards for Sewage from Land-based Sewage Treatment Plants (40 CFR 133.102)	Title XIV Standard for Continuous Discharge in Alaskan waters (33 CFR Part 159 Subpart E)
Biochemical oxygen demand (5-day) (mg/L)	7.99*	133		<45[4] <30[5]	<45[4] <30[5]
Total suspended solids (mg/L)	4.49*	627	<150	<45[4] <30[5]	<45[4] <30[5]
pH	99.5% of pH samples between 6.0 and 9.0	90.5% of pH samples between 6.0 and 9.0		between 6.0 and 9.0	between 6.0 and 9.0

[1] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
[2] Based on data collected by the Alaska Cruise Ship Initiative (ACSI) in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[3] The geometric mean of the samples from the discharge during any 30-day period does not exceed 20 fecal coliform per 100 milliliters (ml) and not more than 10 percent of the samples exceed 40 coliform per 100 ml.
[4] The 7-day average shall not exceed this value.
[5] The 30-day average shall not exceed this value. In addition, the 30-day average percent removal shall not be less than 85%.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

2.4.2 Comparison to EPA's National Recommended Water Quality Criteria

EPA compared average effluent concentrations from traditional Type II MSDs and from AWTs (discussed in subsection 2.3 above) to EPA's 2006 National Recommended Water Quality Criteria (NRWQC) for saltwater aquatic life and for human health (for the consumption of organisms only). Analytes that exceed the NRWQC are discussed in greater detail in this subsection.

EPA's NRWQC are recommended concentrations of analytes in a waterbody that are intended to protect human health and aquatic organisms and their uses from unacceptable effects from exposures to these pollutants. The NRWQC are not directly comparable to analyte concentrations in a discharge because NRWQC not only have a concentration component, but also a duration and frequency component. However, comparison of cruise ship wastewater discharges to NRWQC provides a conservative screen of whether these discharges might cause, have the potential to cause, or contribute to non-attainment of the water quality standards in a given receiving water. If the concentration of a given analyte in cruise ship wastewater is less than the NRWQC, the wastewater should not cause, have the potential to cause, or contribute to non-attainment of a water quality standard based on that criterion. If the concentration of a particular analyte in cruise ship wastewater is greater than the NRWQC, additional analysis would determine whether the discharge would cause, have the potential to cause, or contribute to non-attainment of a water quality standard in a given receiving water.

Pathogen Indicators

Sewage may host many pathogens of concern to human health, including *Salmonella, shigella*, hepatitis A and E, and gastro-intestinal viruses (National Research Council, 1993). Sewage contamination in swimming areas and shellfish beds pose potential risks to human health and the environment by increasing the rate of waterborne illnesses (Pruss, 1998; Rees, 1993; National Research Council, 1993). Shellfish feed by filtering particles from the water, concentrate bacteria and viruses from the water column, and pose the risk of disease in consumers when eaten raw (National Research Council, 1993; Wu, 1999).

The NRWQC for pathogen indicators references the bacteria standards in EPA's 1986 *Quality Criteria for Water*, commonly known as the Gold Book. The Gold Book standard for bacteria is described in terms of three different waterbody use criteria: freshwater bathing, marine water bathing, and shellfish harvesting waters. The marine water bathing and shellfish harvesting waterbody use criteria, shown in Table 2-12, were used for comparison with cruise ship discharge concentrations.

Table 2-12. National Recommended Water Quality Criteria for Bacteria

Waterbody Use	Gold Book Standard for Bacteria
Marine Water Bathing	Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the enterococci densities should not exceed 35 per 100 ml; no sample should exceed a one sided confidence limit (C.L.) using the following as guidance: 1) Designated bathing beach 75% C.L. 2) Moderate use for bathing 82% C.L. 3) Light use for bathing 90% C.L. 4) Infrequent use for bathing 95% C.L. based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.7 as the log standard deviation.
Shellfish Harvesting Waters	The median fecal coliform bacterial concentration should not exceed 14 MPN per 100 ml with not more than 10% of samples exceeding 43 MPN per 100ml for the taking of shellfish.

Enterococci data were unavailable for traditional Type II MSD effluent. Fecal coliform data for Type II MSD effluent consistently exceeded the NRWQC for shellfish harvesting waters. Fecal coliform concentrations in traditional Type II MSD effluent averaged 2,040,000 MPN/100 mL (total of 92 samples, calculation used detection limits for nondetected results) and ranged from 0 to 24,000,000 MPN/100 mL. Over 50% of the collected samples exceeded 43 MPN/100 mL. Given the consistent exceedance of the NRWQC for bacteria, traditional Type II MSD effluent may cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water. Effluent bacteria concentrations from AWT systems are consistently below the pathogen standards in Table 2-12 and therefore should not cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water.

Conventional Pollutants and Other Common Analytes

Conventional pollutants and other common analytes that have a saltwater aquatic life or human health (for the consumption of organisms) narrative NRWQC include oil and grease, settleable residue, total suspended solids (TSS) (see Table 2-13), and temperature (see Tables 2-13 and 2-14). In addition, the NRWQC include a numeric standard for total residual chlorine (see Table 2-15).

Table 2-13. Narrative National Recommended Water Quality Criteria for Conventional Pollutants and Other Common Analytes

Analyte	Gold Book Standard
Oil and Grease	For aquatic life: (1) 0.01 of the lowest continuous flow 96-hour LC50 to several important freshwater and marine species, each having a demonstrated high susceptibility to oils and petrochemicals. (2) Levels of oils or petrochemicals in the sediment which cause deleterious effects to the biota should not be allowed. (3) Surface waters shall be virtually free from floating nonpetroleum oils of vegetable or animal origin, as well as petroleum-derived oils.
Settleable and Suspended Solids	Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life.
Temperature	Marine Aquatic Life: In order to assure protection of the characteristic indigenous marine community of a waterbody segment from adverse thermal effects, the maximum acceptable increase in the weekly average temperature resulting from artificial sources is 1°C (1.8 °F) during all seasons of the year, providing the summer maxima are not exceeded; and daily temperature cycles characteristic of the waterbody segment should not be altered in either amplitude or frequency. Summer thermal maxima, which define the upper thermal limits for the communities of the discharge area, should be established on a site-specific basis.

Oil and Grease

Annual worldwide estimates of petroleum input to the sea exceed 1.3 million metric tonnes (about 380 million gallons) (National Research Council, 2003). Levels of oil and grease of any kind can cause a variety of environmental impacts including the drowning of waterfowl because of loss of buoyancy, preventing fish respiration by coating their gills, asphyxiating benthic organisms from surface debris settling on the bottom, and reducing the natural aesthetics of waterbodies (EPA, 1986).

EPA does not have information on traditional Type II or AWT effluent that would allow us to directly evaluate the narrative NRWQC for oil and grease. Oil and grease data were unavailable for traditional Type II MSD effluent. Oil and grease (as measured by Hexane Extractable Material or HEM) was detected in about 10% of the samples from AWT effluent, with detected amounts ranging between 5.2 and 19 mg/L. EPA did not observe any floating oils in their effluent samples, therefore it is unlikely that there would be floating oils in the receiving water

(ADEC/Coast Guard did not provide a visual description of their samples to indicate if floating oils were observed). Based on the limited amount of information available, it seems unlikely that AWT effluent would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water.

Settleable and Suspended Solids

Levels of solids, either settleable or suspended, in untreated or inadequately treated sewage may harm marine organisms by reducing water clarity and available oxygen levels in the water column. In addition, solids can directly impact fish and other aquatic life by preventing the successful development of eggs and larva, blanketing benthic populations, and modifying the environment such that natural movements and migration patterns are altered (EPA, 1986).

EPA did not directly evaluate traditional Type II or AWT effluent against the narrative NRWQC for settleable and suspended solids because the criterion is based on conditions in a specific waterbody. Total suspended solids were detected in traditional Type II MSD effluent at levels ranging from 200 to 1,480 mg/L, with an average of 627 mg/L. The detected values are substantially higher than the discharge standards for sewage from land-based sewage treatment plants (7-day average shall not exceed 45 mg/L). A site-specific evaluation would determine if these discharge concentrations would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water.

In contrast, the majority of effluent data from AWTs were nondetect values for both settleable solids and total suspended solids. It is unlikely that effluent from AWT systems would cause or contribute to an exceedance of water quality standards in a given receiving water.

Temperature

Temperature changes can directly affect aquatic organisms by altering their metabolism, ability to survive, and ability to reproduce effectively. Increases in temperature are frequently linked to acceleration in the biodegradation of organic material in a waterbody, which increases the demand for dissolved oxygen and can stress local aquatic communities.

EPA did not directly evaluate traditional Type II or AWT effluent against the narrative NRWQC for temperature because the criterion is based on conditions in a specific waterbody. The average temperature from AWT effluent measured in Alaska was 31.3 °C (temperature data were not available for traditional Type II MSD effluent). Local waterbody temperatures would be needed to determine if the temperature from AWT effluent would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water. Table 2-14 provides a few examples of the water temperatures observed in various coastal waters across the United States. The average temperature for AWT effluent is similar to the summer temperatures at some of these locations, and exceeds the winter temperatures by around 10 to 30 degrees Celsius. A site-specific evaluation would determine if the cruise ship discharge volume is significant enough to alter the temperature of a given waterbody. However, considering the size of coastal waterbodies where cruise ships operate, it is unlikely that cruise ship effluent temperatures would cause an increase in waterbody temperature that would exceed the NRWQC.

Table 2-14. Seasonal Coastal Water Temperatures in °C Across the United States

Location	State	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Boston Harbor	MA	4.44	2.22	5.00	7.22	12.22	16.11	18.89	20.00	18.89	14.44	10.56	5.56
Baltimore	MD	4.44	2.78	6.11	10.56	16.11	21.11	25.00	26.11	25.00	18.89	12.22	6.11
Miami Beach	FL	21.67	22.78	23.89	25.56	26.67	28.89	30.00	30.00	28.89	28.33	24.44	22.78
Key West	FL	20.56	21.11	23.89	26.11	27.78	30.00	30.56	30.56	30.00	28.33	24.44	22.22
Seattle	WA	8.33	7.78	7.78	8.89	10.00	11.67	12.78	13.33	13.33	12.22	10.56	9.44
Los Angeles	CA	14.44	14.44	15.56	15.56	16.11	16.67	18.33	20.00	19.44	18.89	17.78	15.56
Galveston	TX	12.22	12.78	16.11	21.67	25.56	28.33	30.00	30.00	28.33	23.89	19.44	15.00
Juneau	AK	2.22	2.22	2.78	4.44	7.78	10.56	11.11	10.56	9.44	6.67	4.44	3.33
Honolulu	HI	24.44	24.44	24.44	24.44	25.56	26.11	26.67	26.67	27.22	27.22	26.11	25.00

Source: National Oceanographic Data Center Coast Water Temperature Guide (www.nodc.noaa.gov/dsdt/wtg12.html)

Total Residual Chlorine

Chlorine is extremely toxic to aquatic organisms. Chlorine concentrations as low as 3 µg/L can result in a high mortality rate for some species (EPA, 1984a). In fish, exposure to low levels of total residual chlorine (<1,000 µg/L) can cause avoidance behavior, respiratory problems, and hemorrhaging (Vetrano, 1998). Fish may recover once removed from the chorine environment, but the severity of the reaction and chance of death increases as the concentration of total residual chlorine increases (Booth et al., 1981). Studies have shown that continuous chlorination can lead to a shift in the composition of phytoplankton communities, thus altering the benthic and fish communities that feed on them (Sanders and Ryther, 1980).

Both traditional Type II MSD and AWT effluent concentrations exceed the NRWQC for total residual chlorine at the end of the pipe (see Table 2-15). A site-specific evaluation would determine if these discharge concentrations would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water. As discussed in subsection 2.4.1 above, this may be less of a concern for AWTs because detection limits for these samples are generally higher than the NRWQC (the minimum detection limit reported by most analytical labs is 100 µg/L). This may artificially increase the average concentration from AWTs because the detection limit was used for nondetect samples when calculating an average, and the majority of samples from AWTs were nondetect samples (total residual chlorine was detected in only 41 of 547 samples in Alaska).

Detection limits do not pose a similar issue for traditional Type II MSD discharges, as total residual chlorine was detected in 12 of 18 traditional Type II MSD effluent samples at concentrations above the minimum detection limit. The source for total residual chlorine in traditional Type II MSD effluent is the chlorination step in wastewater treatment. Chlorination is used in traditional Type II MSDs to meet fecal coliform and total suspended solids standards by killing pathogens in the wastewater.

Table 2-15. Comparison of Traditional Type II MSD and AWT Effluent to Numeric National Recommended Water Quality Criteria for Total Residual Chlorine

Analyte	Average Concentration in Traditional Type II MSD Effluent[1]	Average Concentration in AWT Effluent[2]	NRWQC Criteria Maximum Concentration (CMC)	NRWQC Criterion Continuous Concentration (CCC)
Total Residual Chlorine (µg/L)	1,070*	338*	13	7.5

[1] Based on data collected by the Alaska Cruise Ship Initiative (ACSI) in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Metals

In the aquatic environment, elevated concentrations of metals can be toxic to many species of algae, crustaceans, and fish. Exposure to metals at toxic levels can cause a variety of changes in biochemical, physiological, morphological, and behavioral pattern in aquatic organisms. One of the key factors in evaluating metal toxicity is the bioavailability of the metal in a waterbody. Some metals have a strong tendency to adsorb to suspended organic matter and clay minerals, or to precipitate out of solution, thus removing the metal from the water column. The tendency of a given metal to adsorb to suspended particles is typically controlled by the pH and salinity of the waterbody. If the metal is highly sorbed to particulate matter, then it is likely not in a form that organisms can process. Therefore, a high concentration of a metal measured in the total form may not be an accurate representation of the toxic potential to aquatic organisms. Accordingly, NRWQC for the protection of aquatic life for metals are typically expressed in the dissolved form. In contrast, human health criteria (for the consumption of organisms) for metals are commonly expressed in the total metal form. The use of total metals for human health criteria is because human exposure to pollutants is assumed to be through the consumption of organisms, where the digestive process is assumed to transform all forms of metals to the dissolved phase, thus increasing the amount of biologically available metals.

ACSI did not report any dissolved metal data for traditional Type II MSD effluent. ACSI data for total metals in traditional Type II MSD effluent were consistently below the NRWQC for human health (for the consumption of organisms). AWT effluent data show most metals at levels below the NRWQC for human health and aquatic life. Several dissolved metals that are common components of ship piping—copper, nickel, and zinc—were found at levels approximately one to four times above NRWQC for aquatic life (see Table 2-16). A site-specific evaluation would determine if these discharge concentrations would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water. However, as discussed in section 2.4.3 below, these analytes would likely meet NRWQC after initial mixing (about 1 to 7 meters from the ship) even when a vessel is at rest.

Table 2-16. Comparison of AWT Effluent to National Recommended Water Quality Criteria for Metals

Analytes that Exceed One or More NRWQC[1]	Average Concentration in Cruise Ship AWT Effluent[2]	NRWQC Criteria Maximum Concentration (CMC)	NRWQC Criterion Continuous Concentration (CCC)
Copper (Dissolved) (µg/L)	13.7*	4.8	3.1
Nickel (Dissolved) (µg/L)	13.3*	74	8.2
Zinc (Dissolved) (µg/L)	185*	90	81

[1] Analytes are not listed in this table if the number of detects was not considered representative of cruise ship effluent (i.e., less than 10% of samples), if the data were not in the correct form for comparison with NRWQC, or if the average concentration was driven by detection limits.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Semivolatile and Volatile Organics

Tables 2-17 and 2-18 present the organic compounds detected in traditional Type II MSD and AWT effluent that exceed NRWQC. Note that effluent from traditional Type II MSDs was not tested for all organic compounds that have a NRWQC. The magnitude of the exceedances of NRWQC for the semivolatile and volatile organic compounds discussed in this subsection ranged from one to four times the standard. A site-specific evaluation would determine if effluent from traditional Type II MSDs or AWTs would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water. However, as discussed in section 2.4.3 below, these analytes would likely meet NRWQC after initial mixing (about 1 to 7 meters from the ship) even when a vessel is at rest.

Table 2-17. Comparison of Traditional Type II MSD Effluent to National Recommended Water Quality Criteria for Semivolatile and Volatile Organics

Analytes that Exceed One or More NRWQC[1,2]	Average Concentration in Traditional Type II MSD Effluent[3]	NRWQC Human Health (for the Consumption of Organisms)
Bis(2-ethylhexyl) phthalate (µg/L)	3.5*	2.2
Carbon tetrachloride (µg/L)	2.0*	1.6
Bromodichloromethane (µg/L)	34*	17
Dibromochloromethane (µg/L)	27*	13
Tetrachloroethylene (µg/L)	13*	3.3

[1] Analytes are not listed in this table if the number of detects was not considered representative of cruise ship effluent (i.e., less than 10% of samples), if the data were not in the correct form for comparison with NRWQC, or if the average concentration was driven by detection limits.
[2] Traditional type II MSD effluent data were not available for all analytes that have a NRWQC. Therefore, this table may not include all analytes that exceed NRWQC.

[3] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Table 2-18. Comparison of AWT Effluent to National Recommended Water Quality Criteria for Semivolatile and Volatile Organics

Analytes that Exceed One or More NRWQC[1]	Average Concentration in Cruise Ship AWT Effluent[2]	NRWQC Human Health (for the Consumption of Organisms)
Tetrachloroethylene (μg/L)	5.59*	3.3

[1] Analytes are not listed in this table if the number of detects was not considered representative of cruise ship effluent (i.e., less than 10% of samples), if the data were not in the correct form for comparison with NRWQC, or if the average concentration was driven by detection limits.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Bis(2-ethylhexyl) phthalate is a manufactured chemical that is commonly added to plastics to make them flexible and can be found in a variety of common products such as wall coverings, tablecloths, floor tiles, furniture upholstery, and shower curtains. Carbon tetrachloride is used as an industrial and chemical solvent in a variety of applications such as household cleaning fluids and as a degreaser in industrial settings. Bromodichloromethane and dibromochloromethane are chlorine byproducts that are generated when chlorine used to disinfect drinking water and wastewater reacts with natural organic matter and/or bromide in water. Tetrachloroethylene is widely used in dry cleaning and for metal-degreasing. The likely source of tetrachloroethylene in cruise ship effluent is in the condensate from onboard dry cleaning operations. (Spent tetrachloroethylene from dry cleaning is not discharged with cruise ship wastewater and is handled as a separate stream for disposal.)

Nutrients

Sewage contains nutrients, such as nitrogen and phosphorus, which are important elements for aquatic plant and algae growth. The influx of excess nutrients can negatively affect marine ecosystems, resulting in diebacks of corals and seagrasses, eutrophication (oxygen-depleted "dead" zones), and increases in harmful algal blooms that can alter the seasonal progression of an ecosystem and choke or poison other plants and wildlife (National Research Council, 1993).

Ammonia is the only nutrient for which there is a numeric saltwater or human health (for the consumption of organisms) NRWQC. In the aquatic environment, ammonia exists in the unionized (NH_3) and ionized (NH_4^+) form. Unionized ammonia is the more toxic form of the two with several factors such as pH, temperature, and salinity determining the toxicity to aquatic organisms. Acute levels of NH_3 that are toxic to fish can a cause a loss of equilibrium, hyperexcitability, and increased breathing, cardiac output, and oxygen uptake (WHO, 1986). Extreme concentrations can cause convulsions, coma, and even death.

The marine NRWQC references EPA's1989 *Ambient water quality criteria for ammonia (saltwater)* document, which includes a matrix table for ammonia standards based on the pH, temperature, and salinity of a waterbody. Table 2-19 presents the average concentration of ammonia in traditional Type II MSD and AWT effluent. Table 2-20 presents examples of the ammonia NRWQC calculated from pH, temperature, and salinity for some cruise ship ports of call in the United States.

Table 2-19. Ammonia Concentration in Traditional Type II MSD and AWT Effluent

Analyte	Average Concentration in Traditional Type II MSD Effluent[1]	Average Concentration in Cruise Ship AWT Effluent[2]
Ammonia (NH3-N µg/L)	145,000	36,600*

[1] Based on data collected by ACSI in 2000; of 21 vessels sampled, 19 had traditional Type II MSDs and 2 had prototype reverse osmosis treatment systems.
[2] Based on data collected by ADEC/Coast Guard from 2003 to 2005; data collected by EPA in 2004; and data collected through EPA's 2004 cruise ship survey.
* Average includes at least one nondetect value; this calculation uses detection limits for nondetected results.

Table 2-20. Calculated Ammonia NRWQC for Some Cruise Ship Ports of Call in the United States

Location	State	pH	Average Temperature (°C)	Salinity (psu)	Ammonia NRWQC Criteria Maximum Concentration (CMC) (NH3-N µg/L)[4]	Ammonia NRWQC Criterion Continuous Concentration (CCC) (NH3-N µg/L)[4]
Galveston Bay[1]	TX	8.1	29.0	14.0	2,140	321
Honolulu Harbor[1]	HI	8.0	25.5	34.4	4,110	617
Los Angeles Harbor[1]	CA	8.1	17.4	32.6	7,110	1,110
Port of Miami[2]	FL	8.0	25.3	32.0	4,110	617
Monterey Harbor[1]	CA	8.1	15.3	32.9	6,860	1,070
New York Harbor[1]	NY	7.5	22.1	22.9	11,500	2,960
Southeast Alaska[3]	AK	7.8	12.5	20.0	15,600	2,340
Portland Harbor[1]	ME	7.8	19.4	29.6	9,040	1,400

[1] Data source: EPA's EMAP National Coastal Database (http://oaspub.epa.gov/coastal/coast.search)
[2] Data source: South Florida Water Management District Monitoring Stations (http://glades.sfwmd.gov/pls/dbhydro_pro_plsql/water_quality_interface.main_page)
[3] Data source: Draft State of Alaska Department of Environmental Conservation Large Commercial Passenger Vessel Wastewater Discharge General Permit No. 2007DB0002 (www.dec.state.ak.us/water/cruise_ships/pdfs/PN%20Version%20LPV%20WWGP%20-%20DRAFT.pdf)
[4] Ammonia standards were calculated based on pH, temperature, and salinity values for each waterbody using the matrix table provided in EPA's 1989 *Ambient water quality criteria for ammonia (saltwater)* document. In cases where measured values fell between column and row headings for pH and temperature the standard was approximated based on the closest value. In addition, the ammonia standards were converted from µg-NH_3/L to µg-NH_3-N/L by multiplying the standard by 0.822.

Average effluent concentrations of ammonia from traditional Type II MSDs and AWTs exceed all of the waterbody ammonia standards presented in Table 2-20. Although ammonia standards can vary from waterbody to waterbody, there is only a small range of pH, temperature, and salinity values that result in an ammonia standard that traditional Type II MSD and AWT average effluent concentrations will not exceed. This suggests that ammonia concentrations in traditional Type II MSDs and AWTs effluent at the end-of-pipe are likely to exceed NRWQC regardless of the receiving water parameters used to calculate the criterion. A site-specific evaluation would determine if these discharge concentrations would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water.

In addition to the ammonia standard, EPA has established criteria for the general category of nutrients. The NRWQC references EPA's nutrient ecoregional criteria documents for lakes and reservoirs, rivers and streams, and wetlands. At this time, EPA has not developed ecoregional criteria for estuarine or marine systems; however, EPA has developed a guidance manual for establishing nutrient criteria in estuarine and marine waters. In the 2001 *Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters*, EPA states that:

> "nutrient criteria need to be established on an individual estuarine or coastal water system basis and must be appropriate to each waterbody type. They should not consist of a single set of national numbers or values because there is simply too much natural variation from one part of the country to another. Similarly, the expression of nutrient enrichment and its measurement vary from one waterbody type to another. For example, streams do not respond to phosphorus and nitrogen in the same way that lakes, estuaries or coastal waters."

To account for the extreme variations in residence time, salinity, and density profiles observed in estuaries and coastal waters, EPA recommends using a reference condition approach for setting nutrient criteria in marine waters (EPA, 2001). A reference condition is defined as the comprehensive representation of data, such as median total nitrogen, total phosphorus, and chlorophyll values, from minimally impacted or "natural" sites on a waterbody or from within a similar class of waterbodies (EPA, 2001). Once a reference condition is established, modeling and local expert analysis of the data are used to establish a criterion for each nutrient (e.g., total nitrogen and total phosphorus) to reflect the optimal nutrient condition for the waterbody in the absence of cultural impacts.

Although there are no national standards for nutrient criteria in coastal waters, some states have established waterbody-specific or state-wide standards for nutrients based on site-specific evaluations. For example, Hawaii has established nutrient criteria for several different categories of coastal waters, such as estuaries, embayments, open coastal waters, oceanic waters, and specifically for Pearl Harbor. Nutrient criteria in Hawaii include limitations on total nitrogen, ammonia, nitrate/nitrite, total phosphorus, chlorophyll, and turbidity. Hawaiian nutrient criteria are expressed as follows: criteria values which the geometric mean of samples is not to exceed, criteria values which sample values are not to exceed more than 10% of the time, and criteria values which sample values are not to exceed more than 2% of the time. This tiered approach to nutrient criteria allows for the natural variability in nutrient concentrations in the environment. Table 2-21 provides a subset of the criteria values for the different waterbody classifications in Hawaii. Stakeholders interested in site-specific nutrient criteria should consult their state water quality standards for additional information on state-wide or waterbody-specific nutrient criteria.

Table 2-21. Hawaii Nutrient Criteria Values Which the Geometric Mean of Samples Is Not to Exceed

Analyte	All Estuaries Except Pearl Harbor	Pearl Harbor	Embayments	Open Coastal Waters	Oceanic Waters
Total Nitrogen (µg/L)	200	300	200[1] 150[2]	150[1] 110[2]	50
Ammonia Nitrogen (µg N/L)	6	10	6[1] 3.5[2]	3.5[1] 2[2]	1
Nitrate + Nitrite (µg N/L)	8	15	8[1] 5[2]	5[1] 3.5[2]	1.5
Total Phosphorus (µg p/L)	25	60	25[1] 20[2]	20[1] 16[2]	10
Chlorophyll (µg/L)	2	3.5	1.5[1] 0.5[2]	0.3[1] 0.15[2]	0.06
Turbidity (NTU)	1.5	4	1.5[1] 0.4[2]	0.5[1] 0.2[2]	0.03

[1] Wet criteria apply when the average fresh water inflow from the land equals or exceeds 1% of the embayment volume per day.
[2] Dry criteria apply when the average fresh water inflow from the land is less than 1% of the embayment volume per day.

2.4.3 Mixing & Dilution

Although average analyte concentrations in Type II MSD and AWT discharges from cruise ships exceed several NRWQC at the end-of-pipe, the mixing and dilution that occurs following discharge also is relevant to an evaluation of potential environmental impact.

Dilution at Rest

A Science Advisory Panel created by the Alaska Cruise Ship Initiative (ACSI) used the Cornell Mixing Zone Expert System (CORMIX) model to estimate dilution of effluent achieved when a vessel is at rest. Their modeling showed that a discharge rate of 50 m^3/hr yields a dilution factor of 36 at a distance of about 4.5 m from the ship, and a dilution factor of 50 at 7 m from the ship after 43 seconds (ADEC, 2002, Appendix 8, footnote 50).

The Alaska Department of Environmental Conservation (ADEC) modeled the dilution of large cruise ship effluent during stationary discharge under a very conservative scenario (a neap tide in Skagway Harbor), using the Visual Plumes model. Their modeling showed the dilution factors ranging from 5 to 60, which would occur between 1 and 7 meters from the ship (ADEC, 2004).

The initial dilution estimated by ACSI and ADEC for a vessel at rest suggests that most of the pollutants in traditional Type II MSD effluent that were above NRWQC at the end-of-pipe would likely meet NRWQC after initial mixing when the vessel is at rest. However, for three pollutants–fecal coliform (see Table 2-12 and discussion below), total residual chlorine (see Table 2-15), and ammonia (see Tables 2-19 and 2-20)–end-of-pipe discharge levels are high enough that they may not meet NRWQC after initial mixing when the vessel is at rest. A site specific evaluation would determine if these discharge concentrations would cause, have the potential to cause, or contribute to non-attainment of water quality standards in a given receiving water.

As discussed in subsection 2.4.2 above, a few dissolved metals, tetrachloroethylene, chlorine, and ammonia in the effluent from AWTs may exceed certain National Recommended Water Quality Criteria (NRWQC) at the end-of-pipe. In the case of the metals and tetrachloroethylene, the exceedances at the end-of-pipe were approximately one to four times the NRWQC. Therefore, these analytes would likely meet NRWQC after initial mixing when the vessel is at rest, based on the initial dilution factors discussed above. In the case of chlorine, the exceedance was 45 times the most stringent NRWQC. However, the detection limit for chlorine is generally about 13 times greater than the NRWQC, and thus may artificially increase the average concentration from AWTs (because the detection limit is used for nondetect samples and chlorine was only detected in 41 of 547 samples). Therefore, chlorine from AWT effluent also may meet NRWQC after initial mixing in most cases.

The NRWQC for ammonia depends on pH, temperature, and salinity of the waterbody, resulting in a large range of potential values for cruise ship ports around the country (see Table 2-20). Consequently, the amount of potential exceedance from AWTs at the end-of-pipe varies, but the range based on the values presented in Table 2-20 is 2 to 114 times, and in most cases is less than 34 times the calculated NRWQC. Therefore, ammonia from AWTs would likely meet most water quality standards after initial mixing when the vessel is at rest, based on the initial dilution factors discussed above.

It is important to note that the initial mixing estimates discussed above are based on ship-specific and waterbody-specific input parameters such as discharge port size, effluent flow, waterbody temperature, and salinity. Therefore, they are not necessarily representative of the dilution factors that would be achieved by cruise ships in other ports of call in the United States. Site-specific and ship-specific calculations would be needed to determine the dilution for ships in other locations.

Dilution Underway

For vessels underway, there is significant additional dilution due to movement of the vessel and mixing by ship propellers. In 2001, EPA conducted dye dispersion studies behind four large cruise ships while underway off the coast of Miami, Florida. The results of this study indicate that dilution of discharges behind cruise ships moving at between 9.1 and 17.4 knots are diluted by a factor of between 200,000:1 and 640,000:1 immediately behind the boat (EPA, 2002). Based on these dilution factors, effluent from traditional Type II MSDs and AWTs would likely meet all NRWQC while underway.

Using this information, the ACSI Science Advisory Panel determined that the dilution for a ship underway is a function of the speed of the cruise ship, the rate of wastewater discharge, the beam (i.e., width) of the cruise ship, and the draft (i.e., depth) of the cruise ship, according to the following equation:

$$\text{Initial Dilution Factor for Ships Underway} = \frac{4 * (\text{Ship Width} \cdot \text{Ship Draft} \cdot \text{Ship Speed})}{\text{Volume Discharge Rate}}$$

2.4.4 Potential Treatment Technologies in Addition to AWTs

As part of its assessment of the large cruise ship sewage and graywater discharge standards in Alaska, EPA is evaluating upgrades to AWTs and technologies that could be added on to AWTs that would improve the quality of the treated effluent in terms of nutrients, metals, and temperature. These technologies have not been used or tested on cruise ships for the treatment of sewage or graywater. However, EPA believes these technologies are potentially feasible for this application because they currently are used in other shipboard applications or because they currently are used in land-based wastewater treatment facilities and could be adapted for shipboard application. Use of these technologies onboard large cruise ships would require engineering studies to adapt existing designs and materials selection (e.g., metallurgy, membrane and resin selection, loading rates, reliability, space constraints), operating parameters (e.g., pressures, temperatures, service and maintenance cycles), and training for operating personnel to ensure effective and consistent performance and minimize operating costs.

Nutrient Removal Technologies

<u>*Ammonia Removal by Biological Nitrification*</u>

Biological nitrification is a two-step process that converts ammonia to nitrate using nitrifying autotrophic bacteria (*nitrosomonas* and *nitrobacter*) in the aerobic activated sludge process. The equation below shows the two-step conversion of ammonia to nitrate in the treatment process (Metcalf & Eddy, 1991).

$$\text{Step 1: } NH_4^+ + 3/2O_2 \rightarrow NO_2^- + 2H^+ + H_2O$$
$$\text{Step 2: } NO_2^- + 1/2O_2 \rightarrow NO_3^-$$

All activated sludge processes, including those sampled on the cruise ships, have nitrifying bacteria present, although their numbers are much lower than the typical microorganisms that use organic carbon (measured as BOD_5) as their food source. To enhance ammonia removal in the combined carbon oxidation and nitrification process, land-based sewage treatment plants (publicly owned treatment works (POTWs)) have made both equipment modications and operational changes. These enhancements have allowed POTWs to achieve ammonia nitrogen levels much less than one mg/L, with a corresponding increase in effluent nitrate concentration.

Cruise ships would require equipment modifications and operational changes to enhance existing AWTs. Possible equipment modifications would include increased hydraulic retention time and additional aeration equipment to increase the amount of oxygen transferred to the activated sludge process. Possible operational modifications would include longer sludge retention times and optimized temperature, pH, and alkalinity control.

Nitrification converts ammonia to nitrate, but does not reduce total nitrogen.

Total Nitrogen Removal by Ion Exchange

Ion exchange for ammonia removal from cruise ship effluent is a process in which effluent from the UV disinfection system would be passed through a cylindrical tank containing a weak-acid ion exchange resin. Ammonia ions (NH_4^+) present at neutral pH would become bound to the resin due to the negative charge on the resin. When the resin is fully saturated with ammonia ions, it could be either regenerated onboard using a highly-concentrated salt solution or regenerated shore side by a waste management company. Theoretically, ion exchange could remove 100% of ammonia. However, wastes generated from resin regeneration onboard would have to be appropriately managed, including an assessment against the RCRA hazardous waste regulations at 40 CFR 262.11 (see Section 6 for further discussion). The costs and potential environmental concerns associated with management of these wastes would need to be considered as part of the assessment of this technology.

Cruise ships would need to either purchase and install the add-on ion exchange technology and all necessary ancillary equipment, or rent ion exchange canisters from a vendor (who would handle resin regeneration) and purchase and install all necessary ancillary equipment. Operating and maintenance costs would include rental and labor for exchange of the rental units (if applicable), labor and salt brine costs for onboard regeneration (if applicable), operating labor, electrical costs, and maintenance equipment costs.

Ion exchange would remove ammonia from the wastewater, thereby reducing total nitrogen in the effluent. (This compares to biological nitrification, which does not reduce total nitrogen but instead converts one form of nitrogen to another—relatively toxic ammonia to relatively nontoxic nitrate.) Ion exchange would not remove other (nonionic) forms of nitrogen, such as nitrate/nitrite and organic nitrogen. However, these forms are present at only low concentrations in AWT effluent. The average nitrate/nitrite concentration in AWT effluent is 3.32 mg/L, which is less than one-tenth the concentration of ammonia. There is little or no organic nitrogen in the AWT effluent as the concentration of total Kjeldahl nitrogen (which measures organic nitrogen plus ammonia) is almost the same as the concentration of ammonia.

Phosphorus Removal by Chemical Precipitation

Phosphorus is typically removed at sewage treatment plants by one of two methods: enhanced biological uptake or chemical precipitation. Since enhanced biological uptake is a complex process that would require significant modifications to the existing AWT, EPA instead evaluated chemical precipitation. Chemical precipitation of phosphorus is performed at sewage treatment plants by adding ferric chloride, ferrous chloride, or aluminum sulfate (alum) to the aeration tanks of the activated sludge plants. The precipitated iron or aluminum phosphate is removed with the biological sludge. One advantage of ferric or ferrous chloride over alum is that ferric or ferrous chloride typically achieves the same removal as alum using a lower dosage. On average, phosphorus precipitation at sewage treatment plants reduces total phosphorus levels to 0.8 mg/L in the effluent.

Cruise ships would need to purchase and install a chemical feed system to add ferric or ferrous chloride to the AWT bioreactors. Operating and maintenance costs for the chemical feed system would include operating labor, energy, chemicals, and maintenance equipment.

Metals Removal Technologies

Metals Removal by Ion Exchange

Ion exchange for metals removal from cruise ship effluent is a process in which effluent from the UV disinfection system would be passed through a cylindrical tank containing a chelating resin. Metal ions would become bound to the resin. When the resin is fully saturated with metal ions, it could be regenerated onboard with an acid solution. The resulting regeneration solution from metals removal would contain the target metals and have a pH less than two. Alternatively, the resin canister could be regenerated shore side by a waste management company. Theoretically, ion exchange could remove 100% of metals such as copper, nickel, zinc and mercury. However, wastes generated from resin regeneration onboard would have to be appropriately managed, including an assessment against the RCRA hazardous waste regulations at 40 CFR 262.11 (see Section 6 for further discussion). The costs and potential environmental concerns associated with management of these wastes would need to be considered as part of the assessment of this technology.

Cruise ships would need to either purchase and install the add-on ion exchange technology and all necessary ancillary equipment, or rent ion exchange canisters from a vendor (who would handle resin regeneration) and purchase and install all necessary ancillary equipment. Operating and maintenance costs would include rental and labor for exchange of the rental units (if applicable), labor and regeneration solution costs for onboard regeneration (if applicable), operating labor, electrical costs, and maintenance equipment costs.

Metals Removal by Reverse Osmosis

Reverse osmosis is a process in which dissolved ions would be removed from AWT effluent using pressure to force the water through a semipermeable membrane element, which would pass the water but reject most of the dissolved materials. This membrane separation process is expected to remove more than 90% of copper, nickel, zinc, and mercury from AWT effluent (FILMTEC, 1998). Reverse osmosis also would remove other metals and other analytes in cruise ship effluent, including other chlorinated solvents, phenol- and benzene-based organic compounds, and possibly pharmaceuticals and personal care products.

Reverse osmosis is expected to generate a concentrate stream that is approximately 15% of the total influent flow. This concentrate stream would have to be appropriately managed, including an assessment against the RCRA hazardous waste regulations at 40 CFR 262.11 (see Section 6 for further discussion). The costs and potential environmental concerns associated with management of this waste would need to be considered as part of the assessment of this technology.

Cruise ships would need to purchase and install the add-on reverse osmosis technology and all necessary ancillary equipment. Operating and maintenance would include operating labor, electricity, membrane replacement, and membrane cleaning chemicals.

Temperature Control

One method of reducing temperature would be to install a shell and tube heat exchanger that transfers heat from the AWT effluent to a recirculating cold water system. Shell and tube heat exchangers are simply designed, able to operate under varying heat loads, and easily serviced. The recirculating cold water that passes through the heat exchanger to reduce the effluent temperature could be provided by either the vessel's existing chilled water system or by a separate chilled water system designed specifically for heat removal from the final effluent.

Cruise ships would need to purchase and install the add-on heat exchanger, as well as a new chiller if the existing chiller does not provide a sufficient volume of cold water to cool the effluent. Operating and maintenance costs for the heat exchanger system would include operating labor (e.g., start-up and shut-down maintenance at the start and end of the Alaska cruise season), electricity, and maintenance equipment.

2.5 What action is the federal government taking to address sewage from cruise ships?

EPA is evaluating the performance of advanced sewage and graywater treatment systems.
EPA is evaluating the performance of various advanced sewage and graywater treatment systems as part of its effort to assess whether revised or additional standards for sewage and graywater discharges from large cruise ships operating in Alaska are warranted under Title XIV (see subsection 2.2.3). Some of the results of this intensive effort, including sampling four different Advanced Wastewater Treatment systems and a survey questionnaire for all cruise ships operating in Alaska in 2004, are summarized in this report. EPA anticipates making these full analyses publicly available in 2008.

Coast Guard has developed regulations implementing the monitoring requirements of Title XIV.
Under Title XIV, the Coast Guard has implemented an inspection regime that includes sampling of cruise ship sewage and graywater discharges in Alaskan waters. In July 2001, the Coast Guard published a final rule (33 CFR 159.301-321) that outlines its oversight of cruise ships sampling in Alaskan waters.

Coast Guard is conducting a review of its inspection and enforcement policies.
The Coast Guard has started a review of their inspection and enforcement policies and regulations for cruise ship environmental practices. This review includes a survey of inspectors from Coast Guard regions, focusing on MSDs, oil/water separators, and the effectiveness and feasibility of various inspection practices.

California National Marine Sanctuaries propose to prohibit cruise ship sewage discharges.
Under the National Marine Sanctuaries Act (16 U.S.C. § 1431 et seq.), the Monterey Bay, Gulf of the Farallones, and Cordell Bank National Marine Sanctuaries have proposed regulations to

prohibit the discharge of treated and untreated sewage from large vessels, including cruise ships (71 FR 59050, Oct. 6, 2006; 71 FR 59338, Oct. 6, 2006; 71 FR 59039, Oct. 6, 2006). NOAA is currently reviewing the comments on these proposed rules. The Channel Islands National Marine Sanctuary has published a notice of intent (72 FR 40775, July 25, 2007) to revise a proposed action concerning vessel discharges (71 FR 29096, Oct. 5, 2006). The proposed rule containing the revision, which will include a prohibition on treated and untreated sewage from cruise ships, will be published for public comment in the near future.

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